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HYDRAULIC RESEARCH

at

COLORADO STATE UNIVERSITY

Summary of Research Projects

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Compiled by
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Assistant Civil Engineer

Engineering Research
Colorado State University
Fort Collins, Colorado

December 1959

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Summary of Research Projects

The summary of each project follows this outline:

- (a) Title
- (b) Sponsors of the project
- (c) Principal investigator
- (d) Type of research, i. e., basic, applied, etc.
- (e) Description of the research
- (f) Present status, i. e., active, suspended, or completed
- (g) Results
- (h) Publications

The outline above follows that used in the Hydraulic Research Bulletin prepared annually by the National Bureau of Standards, U.S. Department of Commerce. The number preceding many of the titles is the NBS number designation.

- (55) SNOW COURSE MEASUREMENTS AND FORECAST ANALYSIS.
- (b) Soil Conservation Service, Colorado Agricultural Experiment Station.
 - (c) Jack N. Washichek, Snow Survey Supervisor.
 - (d) Field investigations; applied research
 - (e) Systematic measurements of depth and water content of snow at high elevations in Colorado mountain areas for the purpose of forecasting the runoff of the principal rivers of the state 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 2 or more soil moisture stations installed. A period of record must follow before any degree of correlation can be accomplished.
 - (f) Active.
 - (g) Snow measurement data are correlated with runoff. Once the relationship is established, the snow measurement data are used to predict the runoff for the coming season.
 - (h) Colorado Agricultural Experiment Station General Series Papers -- Monthly Snow Survey Reports for the Rio Grande, Colorado and Platte-Arkansas Drainage Basin.

- (821) GROUND-WATER FLUCTUATIONS AND THEIR RELATION TO PUMPING.
- (b) Colorado Agricultural Experiment Station.
 - (c) M. M. Skinner, Assistant Civil Engineer.
 - (d) Field investigation.
 - (e) The work consists of semi-annual measurements of the depth to the water table in about 300 observation wells in the Arkansas and South Platte Valleys in Colorado. Seven continuous recorders are also now in operation. Observation wells are strategically located in pumping areas. Data on power consumption are also gathered for comparison with water-table elevations. The work is coordinated with the Ground Water Branch, U.S.G.S.
 - (f) Active.
 - (g) Water tables in nearly all areas under canals have recovered to normal levels because of favorable surface water supplies during the last few years following the years of short supply in the early 50's. However, water tables have declined in many areas which depend entirely upon ground water for irrigation and have a small natural recharge in comparison to withdrawals.
 - (h) "Water Table Fluctuations in Eastern Colorado", by W. E. Code, Colorado State Univ. Agr. Expt. Sta. Bulletin 500-S, 34 pp., August 1958.

"Leaky Reservoir Aids Water Table", Colorado Farm and Home Research, Vol. 9, No. 1, pp. 3-4, Summer 1958.

(1074) HYDRAULICS OF STILLING BASINS

(b) U.S. Bureau of Public Roads.

(c) G. L. Smith, Assistant Civil Engineer.

(d) Experimental; applied and fundamental.

(e) This study consists of several phases. The first phase, which has been completed, was development of generalized design criteria for stilling basins for cantilevered pipe flow. The stilling basin is a pre-shaped scour hole in an alluvial bed armorplated with well graded riprap. The second phase of the study, which is in progress, is to investigate the efficiency of the armorplated, pre-shaped stilling basin in scour control for different boundary geometry.

(f) Present Status: A project report covering work to date is being written.

(g) Scour in alluvial beds increases with an increase in channel width. The contributing factor to the increased rate of scour is growth and vortex action of secondary currents transverse to the direction of jet flow. Armorplating of channel banks is essential to stability of alluvial channels. Decreasing the slope of the channel banks increases the effectiveness in scour control of the armorplated, pre-shaped stilling basin and banks.

- (h) "Analytical Study of the Mechanics of Scour for Three-dimensional Jet", by Y. Iwagaki, G. L. Smith and M. L. Albertson, Colorado State University, Civil Engineering Dept. Report is now in preparation.
- "The Manifold Stilling Basin", by G. R. Fiala and M. L. Albertson, Colorado State University, Civil Engineering Dept., Report No. CER58MLA35.
- (1837) SEALING OF IRRIGATION CANALS BY BENTONITE SEDIMENTING.
- (b) Colorado State University Experiment Station, USDA - Agricultural Research Service and Irrigation Districts and Companies.
- (c) R. D. Dirmeyer, Jr., Project Leader, Engineering Research, Colorado State University, Fort Collins, Colorado.
- (d) Applied research and development at field sites, supported by laboratory research where needed.
- (e) A pilot model approach is being used which utilizes a procedure development and evaluation trial in a representative canal site for each major irrigated area. Development work with Wyoming high-swell bentonite as a sedimenting agent in sealing irrigation canals is essentially complete. The research and development work is now being concentrated on the use of the low-swell varieties of bentonite as a sedimenting agent for sealing irrigation canals and reservoirs.
- (f) Active.

- (g) The main advantages of the low-swell bentonite over the high-swell varieties are listed as follows: (1) the low-swell varieties are relatively common in many parts of the Western United States and in other areas of the world, whereas the high-swell bentonites are mainly found in Wyoming, and (2) the chemical character of the low-swell bentonites make them compatible with salty soils and hard waters whereas the high-swell bentonites can undergo objectional physical changes when subjected to such conditions.
- (h) "Evaluation Report on Recent Bentonite Sealing Work in Wyoming Canals", by R. D. Dirmeyer, Jr., Colorado State Univ., Civil Engineering Section, March 1959.
- "Testing Bentonite for Sealing Purposes", by R. T. Shen, Colorado State University, Civil Engineering Section, (Colo. Extension Service Circular No. 205 A -- Wyo. Extension Service Circular No. 161).
- "Sealing Sandy Ditches with the Bentonite Dispersion Method", by R. T. Shen, Colorado State University, Civil Engineering Section, (Colo. Extension Service Circular No. 202 A -- Wyo. Extension Service Circular No. 158).
- "Sealing Rocky Ditches with the Bentonite Multiple-Dam Method", by R. T. Shen, Colorado State University, Civil Engineering Section, (Colo. Extension Service Circular No. 203 A -- Wyo.

Extension Service Circular 159).

"Mixing Bentonite for Sealing Purposes", by R. T. Shen, Colorado State University, Civil Engineering Section, (Colo. Extension Service Circular No. 204 A -- Wyo. Extension Service Circular No. 160).

"Sealing Farm Ponds and Reservoirs with Bentonite", by R. T. Shen, Colorado State University, Civil Engineering Section, (Colo. Extension Service Circular No. 206 A -- Wyo. Extension Service Circular No. 162).

(2066) STUDY OF OPEN CHANNEL CONSTRICTIONS IN A SLOPING FLUME.

- (b) U.S. Bureau of Public Roads.
- (c) H. K. Liu, Associate Civil Engineer.
- (d) Experimental; applied.
- (e) Scour at bridge abutments of various shapes and dimensions have been investigated in the laboratory. Natural sediment having mean sizes of approximately 0.45 mm were used in the tests. Sediment supply of mainly bed load varied from zero to less than 1000 ppm.
- (f) Laboratory tests have been completed. Data are being analyzed and compiled. A report is currently being written.
- (g) Criteria for estimating the maximum depth of scour at abutments have been established. The maximum depth of scour, for

given sediment size, is found to depend upon the flow depth, velocity, and abutment length and geometry.

- (h) "Backwater Effects of Bridge Piers and Abutments", by
H. K. Liu, J. N. Bradley, and E. J. Plate, Colorado State
University, Civil Engineering Section, Fort Collins, Colorado.

"Laboratory Observations of Scour at Bridge Abutments", by
H. K. Liu, and M. M. Skinner, Colorado State University,
Fort Collins, Colorado. Bulletin No. 242 Highway Research
Board.

(2277) STUDY OF EVAPORATION FROM SOIL SURFACES IN TERMS
OF SOIL AND MICROMETEOROLOGICAL FACTORS.

- (b) Contributing project to Western Regional Research Project W-32,
"Basic Hydrological Factors Relating to Water Conservation."
- (c) R. A. Schleusener, Assistant Research Engineer.
- (d) Experimental and theoretical. Basic research, part of which
has been used for master's and doctoral theses.
- (e) The project is a comprehensive study of moisture transfer from
soil by evaporation from the soil surface. The immediate
objectives of this investigation are to evaluate the variables
known to affect evaporation from soil in order to determine
those that are most important in the field, and secondly to
search for relationships among the pertinent variables which
will permit quantitative estimates of evaporation from a given
soil under prevailing ambient conditions.

- (f) Continuing.
- (g) Evaporation from soil surfaces has been studied for steady and cyclic ambient atmospheric conditions, using a controlled-environment chamber. Results indicate that under some conditions an inverse relation can exist between the rate of evaporation from a soil in contact with a water table and that from a free-water surface. A theory was developed to explain this phenomenon in terms of a hysteresis property of the soil. This is not in agreement with prior theory which indicates that a limitation from soils should be reached as the evaporation rate increases from a free-water surface. The hysteresis hypothesis suggests that evaporation could be reduced by application of a surface treatment which would promote rapid initial desaturation of the soil surface. Measurements of evaporation from soils subjected to various surface treatments indicate a significant reduction of evaporation can be accomplished by treatment with a gravel mulch.
- (h) "Effect of depth of water table on evaporation from fine sand", M. S. Thesis, by R. W. Staley, Colorado State University, 1957.
- "Factors affecting evaporation from soils in contact with a water table", Ph. D. Dissertation, by Richard A. Schleusener, Colorado State University, 1958.

"A switching arrangement for automatic, remote temperature reading", by Richard A. Schleusener, Colorado State Univ., Agricultural Engineering 40(1):32-33, January 1959.

"The role of hysteresis in reducing evaporation from soils in contact with a water table", by Richard A. Schleusener and A. T. Corey. Journal of Geophysical Research 64(4):469-75, April 1959.

"Relations between evaporativity and evaporation from soils in contact with a water table," by Richard A. Schleusener. A paper presented to the American Meteorological Society Conference on Practical Problems of Modern Meteorology, Denver, 24 September 1958.

(2278) METHODS OF GENERATING A COMPLEX SEA.

(b) David Taylor Model Basin.

(c) Robert E. Glover, Civil Engineer.

(d) Theoretical; applied research.

(e) The research is directed toward the development of ways and means to produce in a wave basin seas which will permit the testing of model ships under conditions representing those encountered by ships on the ocean under storm conditions.

(f) Completed.

- (g) A new type of wave generator was developed which promises to have the ability to produce a replica of an actual storm sea in a circular or rectangular wave basin. The replica sea would cover essentially the entire area of the wave basin.
- (h) "Methods of Creating a Complex Seaway in a Model Basin", by R. E. Glover, prepared for the David Taylor Model Basin under Contract Nonr. 1610(02). Colorado State University, Civil Engineering Department, Report CER58REG43, September 1958.
- "Estimates of Bending Moments and Pressures Due to Slamming", by R. E. Glover, prepared for the David Taylor Model Basin under Contract Nonr 1610(02). Technical Report No. 5. Colorado State University, Civil Engineering Department. August 1957.
- (2279) LABORATORY AND FIELD STUDY OF THE VORTEX TUBE SAND TRAP.
- Cooperative project: Colorado Agricultural Experiment Station and Agricultural Research Service. See U.S. Department of Agriculture, Agricultural Research Service, p. 37.
- (2510) RESEARCH DIRECTED TOWARD THE STUDY OF LOW LEVEL TURBULENCE.
- (b) Air Force Cambridge Research Center.
- (c) J. E. Cermak, Prof. Mechanics and Civil Engineering.
- (d) Experimental; basic research to be used towards a doctoral thesis.

- (e) Measurements of mean velocity, mean temperatures, turbulence intensities and turbulent shear stress profiles were made for turbulent air flow over a plane, rough boundary which was heated. A new wind tunnel with low ambient turbulence level and a test section 6 x 6 x 72 ft was designed and partially completed.
- (f) Completed.
- (g) For the rough, heated surface the velocity defect law for the outer regime of the boundary layer follows the same law for a smooth boundary provided the displacement thickness includes the variation of density with temperature. The temperature distribution can be expressed by a wall law and a temperature-defect law analogous to the velocity-distribution laws.
- (h) "Turbulent Boundary Layer Over Heated and Unheated, Plane, Rough Surfaces", by B. Chanda, Ph. D. Dissertation, Scientific Report No. 1, AFCRC TN-58-428 (Astia-AD 152599), May 1958. 131 pp, Report No. CER58BC21.
- "Wind Tunnel for the Study of Turbulence in the Atmospheric Surface Layer," by J. E. Cermak.
- (2513) WATER AND SEDIMENT MEASURING EQUIPMENT FOR EPHEMERAL STREAMS.
- (b) Rocky Mountain Forest and Range Experiment Station,
Agricultural Research Service and Colorado Agricultural

Experiment Station.

- (c) A. R. Robinson and A. R. Chamberlain, Colorado State University, Fort Collins, Colorado.
 - (d) Experimental; applied research.
 - (e) The present phases of the project are to further develop measuring flumes of trapezoidal shapes for measurement of flows with steep gradients and for a large range of flows.
 - (f) Active.
 - (g) Model results have been compared with prototype measurements with good agreement. A large 1:2 model has been constructed and is presently being tested to better determine the operating characteristics of the prototype structures.
 - (h) "Trapezoidal Measuring Flumes for Determining Discharges in Steep Ephemeral Streams", by A. R. Robinson, Colorado State University Research Foundation, Civil Engineering Section, Fort Collins, Colorado, Report CER59ARR1.
- (2514) STUDY OF RESISTANCE TO FLOW AND SEDIMENT TRANSPORT IN ALLUVIAL CHANNELS.
- (b) U.S. Geological Survey.
 - (c) D. B. Simons, U.S. Geological Survey, Colorado State University, Fort Collins, Colorado.
 - (d) A study of mechanics of flow in alluvial channels using a large recirculating laboratory flume. Experimental, theoretical

and field investigation; basic and applied research.

Some phases of the study are being used to develop masters and doctoral theses; however, the investigation is basically a U.S.G.S. research project.

(e) This investigation consists of a laboratory study which will be followed by a field study of (a) resistance to flow in alluvial channels, (b) sediment transport theory, including the effect of very fine sediment on resistance to flow and sediment transport, and (c) the theory of rapid flow phenomenon in alluvial channels.

(f) Active.

(g) Results: Regimes of flow, forms of bed roughness, resistance to flow relations, and sediment transport relations have been developed for the three sizes of sand investigated.

(h) Publications: U.S.G.S., Water Supply Paper 1498-A, and two (2) A.S.C.E. papers have been submitted for publication.

(2760) METEOROLOGICAL OBSERVATIONS.

(b) Colorado Agricultural Experiment Station and U.S. Weather Bureau.

(c) Maxwell Parshall, Assistant Professor.

(d) Field investigation.

(e) The work is being done to obtain a precise long time record of climatological elements. The elements observed are:

maximum, minimum and current air temperature, wet and dry bulb temperatures for dew point temperature and relative humidity, soil temperatures at 3, 6, 12, 24, 36 and 72 inches, wind direction and velocity at 65 ft and 15 in. above surface, barometric pressure, evaporation from a free water surface, water temperature at surface (maximum, minimum and current), precipitation, cloud cover, dew and frost.

- (f) Continuing.
 - (g) New extreme values of temperature have been recorded recently.
The long time mean temperature is increasing. Precipitation varies widely with no long time trend apparent.
 - (h) Summary of 70 years' record of Meteorological data in process of publication.
- (2761) A STUDY OF THE ECONOMIC EFFECT OF CONTROLLING WATER USE IN AN AREA WHERE SURFACE AND GROUND WATER RIGHTS APPLY TO A SINGLE SUPPLY.
- (b) Colorado Agri. Expt. Sta. and U.S.D.A. Regional Project
W-42. (Revised)
 - (c) M. W. Bittinger, Assistant Civil Engineer.
 - (d) Field investigation; applied research.
 - (e) The engineering phase of this study has as its purpose the determination of the interrelationships of ground water and surface water in an area where both are used for irrigation. An area in the South Platte Valley has been chosen for this study.

The economic phase will be concerned with the implications of various types of legislative controls which may be applied to the situation.

(f) Active.

(g) Most of the field data have been obtained for this study.

Estimates of the amount of pumping over the past thirty years, the amount of water delivered by canals to the study area during the past thirty years and computations of the gain or loss in the river through the years has been made. Various approaches of analyses have been tried to attempt to correlate various hydrological factors to the flow in the river and to the fluctuations of the water table. Various unknowns such as inflow from unmeasured tributaries, excess irrigation water finding its way directly to the river, and temporary bank storage have masked the relationships between hydrologic factors. A theoretical analysis is now underway and will be correlated with field observations. A basic conclusion that has been drawn so far is that pumping of ground water in this particular area of the South Platte Valley has had no major detrimental effect upon surface water rights.

(h) Colorado's Ground Water Problems - Ground Water in Colorado.

Colorado Agricultural Experiment Station Bulletin 504-S,
August 1959.

(2767) EDUCATIONAL FILMS ON OPEN CHANNEL FLOW.

- (b) U.S. Bureau of Public Roads.
- (c) J. R. Barton, Associate Professor.
- (d) Laboratory and field.
- (e) Project involves the making of a color film on open channel flow in connection with highway drainage problems for educational purposes.
- (f) In final editing stage.

(2769) EVALUATION OF FLOWMETERS FOR THE MARTIN COMPANY, DENVER DIVISION.

- (b) The Martin Company, Denver, Colorado.
- (c) Susumu S. Karaki, Assistant Civil Engineer.
- (d) Experimental; applied.
- (e) The purpose of the project is to carry out tests on the dynamic, kinematic and general performance characteristics of various types of flowmeters to be inserted in pipelines. The flowmeters to be considered are the Gulton, Gentile Tube, and Maxson Ultrasonic, impact strain gauge, turbine and rotameters. The fluids under consideration are water, liquid oxygen, liquid nitrogen, JP-4 fuel, RP-1 fuel and MIL-0-5606 hydraulic fluid.
- (f) Active.
- (h) "Evaluation of the Effect of Approach Tubing Size Upon the Calibration of 3/4 inch Turbine Flowmeters", by M. W. Bittinger,

CER57MWB32, November 1957.

"Evaluation of the Effect of Viscosity on the Calibration of Several Flowmeters", by Fred Videon, CER58ARC5, February 1958.

"Evaluation of the Performance of the Gulton Ultrasonic Gentile Tube and Potter Meter 6-424 Flowmeters," by Fred Videon and G. L. Smith, CSURF, June 1958 CER59FV11.

"Evaluation of the Performance of the Floating Rotor Design Flowmeter," by S. S. Karaki and Fred Videon. CSURF, September 1959, CER59SSK45.

(2770) A STUDY OF SHEAR STRESS FLUCTUATIONS AT A LIQUID-SOLID INTERFACE BY MEASUREMENT OF THE ELECTROKINETIC POTENTIAL FLUCTUATIONS :

- (b) National Science Foundation.
- (c) Dr. J. E. Cermak, Prof. Mechanics and Civil Engineering.
- (d) Experimental and theoretical.
- (e) Electrokinetic-potential-fluctuation spectra are being measured for a range of electrode spacings and the regimes in a glass pipe. These data together with auto-correlation data for the electrokinetic potentials will be used to determine the character of shear stress fluctuations at the pipe wall.
- (f) Active.
- (g) Preliminary electrokinetic-potential-fluctuation spectra show similar energy-frequency distributions as do turbulent velocity fluctuations measured in a turbulent flow near a solid wall.

- (h) Ph. D. Dissertation in preparation.
- (2771) DISTRIBUTION OF A WETTING AND NON-WETTING FLUID PHASE IN A POROUS SOLID.
- (b) National Science Foundation.
- (c) Dr. A. T. Corey, presently on temporary assignment as Associate Professor of Civil Engineering, SEATO Graduate School of Engineering, Bangkok, Thailand.
- (d) Experimental and theoretical; basic research.
- (e) The primary objective of this project is to determine the effect of rate of displacement on the distribution of wetting and non-wetting fluid phases in porous solids. Particular emphasis is placed on the situation occurring when a non-wetting phase displaces a wetting phase at various rates. The ultimate aim is to obtain basic information which will enable better techniques to be devised whereby field situations involving flow in porous media can be studied by laboratory models.
- (f) The project is temporarily suspended in the absence of the principal investigation.

(2901) LABORATORY STUDY OF GRAVEL FILTER DESIGN FOR IRRIGATION WELLS .

Cooperative project; Colorado Agricultural Experiment Station and Agricultural Research Service. See U.S. Department of Agriculture, Agricultural Research Service, p.

(2902) DEVELOPMENT IMPROVEMENT OF WATER MEASURING DEVICES.

Cooperative project: Colorado Agricultural Experiment Station and Agricultural Research Service. See U.S. Department of Agriculture, Agricultural Research Service, p.

(3033) DETERMINATION OF PROPER IRRIGATION WELL CONSTRUCTION MATERIALS AND MAINTENANCE PRACTICES FOR OBTAINING MAXIMUM ECONOMICAL LIFE AND PERFORMANCE.

(b) Colorado Agricultural Experiment Station.

(c) M. M. Skinner, Assistant Research Engineer.

(d) Experimental and field investigations; applied.

(e) The study is to determine the extent and causes of partial and complete failures of irrigation wells in Colorado and to develop recommendations for construction methods, materials, maintenance and repairs of irrigation wells.

(f) Active.

(g) Review of literature available indicates a wide variance in recommendations for materials in irrigation-well construction, and in maintenance methods.

(3034) DISTRIBUTION AND CONCENTRATION OF RADIOACTIVE WASTES IN STREAMS BY FLUVIAL SEDIMENTS.

- (b) U.S. Geological Survey.
- (c) A. R. Chamberlain, Chief, Engineering Research, and Acting Dean, College of Engineering.
- (d) Experimental; applied research.
- (e) This study has thus far been divided into two phases. The first phase has been concerned with reviewing the literature and evaluating the status of research on the disposal of radioactive wastes in natural streams. Particular emphasis is placed on problems arising from sediments which are contaminated by sorption of radioactive nuclides. The second phase is concerned with determining dispersion and transport rates of contaminated bed sediments in the field. This is to be accomplished through the usage of sediment particles tagged by radionuclides as tracers.
- (f) Active.
- (g) In the first phase, the factors involved and the present status of research concerning disposal of radioactive wastes in streams are reviewed with respect to: (1) waste characteristics, (2) dispersion theory, (3) sorption by sediments, and (4) sediment transport. Sorption of radiocontaminants by sediments is the rule rather than the exception. Sorption, transport, and distribution of radiocontaminants by sediments

depend on a multiplicity of factors, many of which are very complex and only partially understood. The second phase is in its initial phase, and no results as yet have been achieved.

- (h) "Progress Report: Dispersion and Concentration of Radioactive Wastes by Stream Sediments", by W. W. Sayre, H. P. Guy and A. R. Chamberlain, Report No. CER59ARC26.
- (3035) CONSEQUENCES OF RESTRAINT ON MOTIONS OF A MODEL SHIP.
- (b) U.S. Navy, David Taylor Model Basin.
 - (c) E. F. Schulz, Associate Civil Engineer.
 - (d) Experimental; applied research.
 - (e) The purpose of this project is to obtain experimental data on the influence of restraint on the model motions resulting from wave trains acting on a model ship. Initially the model motions will be restrained and the forces and moments on the model caused by the waves will be measured. A new type wave probe will be used to measure the wave field in the vicinity of the model.
 - (f) Active - continuing.
 - (g) Activity to date has been confined to development of instrumentation. These include the improvement of a capacitance probe which does not touch or disturb the water surface. Six transistorized probe units will be used to measure the waves in the vicinity of the model. Comparison of the records with a record of the undisturbed wave will yield information on the influence of the ship on the waves. A six component balance has been

constructed to measure the forces and moments on the restrained model.

(3036) THE LONGITUDINAL DISTRIBUTION OF FORCES AND MOMENTS ON A RESTRAINED MODEL IN WAVES.

(b) S-3 Panel of Hull Structure Committee, Society of Naval Architects and Marine Engineers.

(c) E. F. Schulz, Associate Civil Engineer.

(d) Experimental; applied research.

(e) The primary objective of this project is to impose pitching and heaving displacements (separately) varying sinusoidally in time upon a model ship and to measure the forces and moments as a function of time. The models are segmented and attached to an oscillating strongback by means of a stiff spring. The force on each end of the segment is sensed by means of an SR4 strain gage. The simultaneous records of the forces on the seven segments may be used to construct a longitudinal shear curve. The longitudinal bending moment is found by graphical integration.

(f) Active.

(g) The Pitching and heaving experiments on a five foot model of a T2-SE-A1 tanker have been completed. The model was oscillated at seven frequencies at rest and at three speeds of advance. The results are being analyzed and will be compared with the analytical findings of Haskind, Havelock and Grimm.

- (3037) STUDY OF ATMOSPHERIC SURFACE LAYER PHENOMENA IN A WIND TUNNEL.
- (b) National Science Foundation.
 - (c) Dr. J. E. Cermak, Prof. Mechanics and Civil Engineering.
 - (d) Experimental and theoretical; basic research.
 - (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. The objective of the program is to relate the turbulent boundary layer structure to the thermal stratification obtained by heating.
 - (f) Active.
 - (g) Heating of the turbulent boundary layer at low Reynolds number 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) "Turbulent Boundary Layer at Low Reynolds Number with Unstable Density Stratification Produced by Heating", by J. E. Cermak, Ph.D. Dissertation, Cornell University.
- (3038) SCOUR BELOW CULVERT OUTLETS.
- (b) Association of American Railroads.
 - (c) G. L. Smith, Assistant Civil Engineer.
 - (d) Experimental and theoretical; fundamental.

- (e) Systematic measurements were made of the velocity profile of a submerged jet impinging upon a normal boundary to determine its influence on jet diffusion. The velocity profile was measured for the various zones of diffusion and along the boundary. The pressure profile was measured radially along the boundary from the point of stagnation to a point where the mean radial velocity is approximately zero.
 - (f) First phase completed.
 - (g) The behavior of the water jet was the same as that found by others for an air jet impinging upon a normal boundary. The error curve serves as a satisfactory representation of diffusion profiles for water jets.
 - (h) Publication: "Flow Characteristics of a Circular Submerged Jet Impinging Normally on a Smooth Boundary", by Michael Poreh, M. S. Thesis, Colorado State University, February 1959.
- (3040) STUDY OF SPUR DIKES FOR HIGHWAY BRIDGE OPENINGS.
- (b) State Highway Departments of Mississippi and Alabama and U.S. Bureau of Public Roads.
 - (c) S. Karaki, Assistant Civil Engineer.
 - (d) Experimental; applied research.
 - (e) Spur dikes at bridge abutments are used to prevent scour at the abutments and adjacent piers. The spur dikes principal

functions are to distribute the flow more uniformly through the bridge opening and to streamline the flow. This experimental study is to determine the relationships between the length and shape of the spur dike with the length of roadway embankment and discharge.

(f) Completed.

(g) The results of the study are presented in a form of a tentative design chart. For normal crossings, it was found that the length of spur dike was a direct function of the length of roadway embankment and discharge. Skewed roadways were also studied and found that spur dike length increased if the roadway skewed upstream and decreased if skewed downstream. Spur dikes for small bridges would require longer spur dikes than that presented by the design chart if the concentration of flow through the bridge was great.

(h) "Progress Report on Hydraulic Model Study for Spur Dikes", by S. Karaki, CSURF, January 1959.

"Hydraulic Model Study of Spur Dikes for Highway Bridge Openings" by Susumu S. Karaki, CSU, Civil Engineering Section, Fort Collins, September 1959, CER59SSK36.

(3041) MAGNITUDE AND FREQUENCY OF FLOODS FROM SMALL WATERSHEDS IN ARID AND SEMI-ARID AREAS.

(b) U.S. Bureau of Public Roads.

- (c) Dr. Richard A. Schleusener, Civil Engineering Section, Colorado State University, Fort Collins, Colorado.
 - (d) Applied Research.
 - (e) The purpose of the study is to develop procedures for predicting the magnitude and frequency of runoff from small watersheds in arid and semi-arid areas.
 - (f) Active.
 - (g) Procedures have been developed for prediction of peak rates of runoff from ungaged watersheds for 10 and 40 - year recurrence intervals for a region in eastern Colorado and adjoining areas.
 - (h) "Preliminary Report on Magnitude and Frequency of Runoff from Small Watersheds in Arid and Semi-Arid Areas", by Richard A. Schleusener, G. L. Smith, and N. Yotsukura, Civil Engineering Section, Colorado State University, CER59RAS39.

"Estimates of Runoff from Small Watersheds in Eastern Colorado, Western Kansas and Nebraska, and Southeastern Wyoming," by Richard A. Schleusener, and G. L. Smith, Civil Engineering Section, Colorado State University, Fort Collins, Colorado. CER59RAS41.
- (a) TRANSFER OF WEATHER DATA TO PUNCH CARDS.
 - (b) U.S.D.A., Soil Conservation Service and U.S. Weather Bureau.
 - (c) Richard A. Schleusener, Assistant Civil Engineer.

- (d) Experimental; applied research.
 - (e) Weather data from 15 stations in eastern Colorado are being placed on IBM punch cards for 30 years of record prior to August 1948.
 - (f) Completed.
 - (g) Daily weather records have been placed on punch cards and from the basis for a library of climatological data in punch card form for 15 stations in eastern Colorado.
 - (h) "Status report on Colorado Cooperative Project in Climatology", by R. A. Schleusener, Civil Engineering Section, Colorado Agricultural Experiment Station in cooperation with the U. S. Weather Bureau and the U.S. Department of Agriculture, Soil Conservation Service. Report CER59RAS30.
- (a) THEORY OF CONSOLIDATION COMBINING PRIMARY AND SECONDARY CONSOLIDATION.
 - (b) National Science Foundation.
 - (c) I. S. Dunn, Associate Professor.
 - (d) Experimental and theoretical; basic research.
 - (e) The study consists of a mathematical analysis of the effect of visco-plastic 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 viscoplastic 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 per cent of deformation.

(f) Active.

(a) RESEARCH ON ARTIFICIAL AND NATURAL RECHARGE OF GROUND WATER IN COLORADO .

(b) Colorado Agricultural Experiment Station.

(c) M. W. Bittinger, Assistant Civil Engineer.

(d) Experimental and applied research.

(e) The research under this project is being carried out in three major parts. Part I consists of an overall analysis of the artificial recharge needs and possibilities in seven major ground water basins in Colorado. This analysis will be based principally upon available information of water supply, water quality, geology, water use and other physical factors. Part II consists of the selection and establishment of field experiments on representative areas within the various ground water basins. Part III consists of theoretical and laboratory studies to extend the information obtained under Part II.

- (f) Active.
- (a) FUNDAMENTAL STUDY OF A SUBMERGED AND NON-SUBMERGED THREE-DIMENSIONAL JET IMPINGING UPON A NORMAL PLANE.
- (b) National Science Foundation.
- (c) George L. Smith, Assistant Civil Engineer, Civil Engineering Department, Colorado State University, and J. E. Cermak, Prof. Mechanics and Civil Engineering, Colorado State University, Fort Collins, Colorado.
- (d) Analytical and experimental; basic research and graduate thesis.
- (e) An experimental study of the axi-symmetrical flow resulting from a jet impinging on a solid boundary. Detailed measurements will be made of the turbulent structure within the boundary layer as well as direct measurements of the boundary shear stress. The data will be used to determine the nature of the boundary layer development and to check the determination of the boundary shear stress by means of the momentum integral equation.
- (f) Active. First phase completed.
- (g) None.
- (h) American Association of Railroads publication. "Flow characteristics of a Circular Submerged Jet Impinging Normally on a Smooth Boundary", by Michael Poreh and J. E. Cermak, Colorado State University, Fort Collins, Colorado.

Proceedings - Midwestern Conference on Fluid and Solid

Mechanics, The University of Texas. September 9, 1959.

- (a) DILLON DAM SPILLWAY
- (b) Tipton and Kalmbach, Inc., Denver, Colorado.
- (c) S. S. Karaki, Assistant, Civil Engineer.
- (d) Experimental; applied research.
- (e) The purpose of the study is to hydraulically test the preliminary design of a morning glory spillway for the Dillon Reservoir and to suggest modifications where necessary consistent with adequate hydraulic performance.
- (f) Completed.
- (g) Excessive negative pressures were measured in the throat and vertical shaft of the spillway and were corrected by installing a deflector above the vertical bend in the tunnel. This served also to streamline the flow through the bend and in the horizontal tunnel. Non-uniform distribution of flow on the crest was solved by installing piers on the crest. The final model design utilized a hydraulic jump stilling basin and deflector designed so that discharges less than 3000 cfs were contained as a hydraulic jump, while large discharges formed a jet off the end of the basin.
- (h) "Hydraulics Model Study of the Morning Glory Spillway, for Dillon Dam", by Susumu S. Karaki, Colorado State University, Research Foundation. June, 1959. CER59SSK21.

- (a) BHUMIPHOL DAM TUNNEL JUNCTION.
 - (b) Engineering Consultants Inc., Denver, Colorado.
 - (c) Susumu S. Karaki, Assistant Civil Engineer.
 - (d) Experimental, applied research.
 - (e) The purpose of this model study is to devise a protective structure within an unlined outlet works tunnel to protect the walls from erosion due to large velocities. Because of the large diameter of the tunnel, and because its use will be limited to two years, a lining for the tunnel is not considered economically justifiable.
 - (f) Active.
 - (g) Preliminary results show that a hydraulic structure can be constructed within the dam, but it must be accompanied by a partial lining to be suitable. Other structures are being tested to determine an economical solution.
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- (a) WIND TUNNEL MODELING OF ATMOSPHERIC DIFFUSION.
 - (b) National Institutes of Health.
 - (c) Dr. J. E. Cermak, Prof. Mechanics and Civil Engineering.
 - (d) Experimental and theoretical.
 - (e) A point source of gas (monomethylamine) located within a turbulent boundary layer formed by the flow of air over a flat plate is used to create a concentration field downstream of

the source. Provisions are also made to heat the boundary from below to produce a boundary layer with unstable density stratification. Sampling of the concentration field is accomplished by drawing measured volumes of gas through water. The solution is then analyzed colorimetrically to determine the methylamine concentration. The concentration fields are being studied in an attempt to determine the effects of non-isotropic boundary layer turbulence on diffusion. An attempt will be made to correlate wind-tunnel-diffusion phenomena to diffusion phenomena in the atmospheric surface layer.

(f) Active.

(a) CLIMATOLOGY OF THE UPPER COLORADO RIVER BASIN.

(b) State of Colorado - Colorado Water Conservation Board.

(c) Dr. Richard A. Schleusener, Civil Engineering Section,
Colorado State University, Fort Collins, Colorado.

(d) Applied research.

(e) The phase of research conducted at Colorado State University involves a study of the variability of certain meteorological parameters in the Upper Colorado River Basin, and their relation to stream flow.

The study at Colorado State University is in cooperation with two other phases being conducted by the University of

Colorado, Bureau of Economic Research and High Altitude Observatory, respectively. In the phase conducted by the Bureau of Economic Research a study is being made of the variability of stream flow of the Colorado River. In the phase being conducted by the High Altitude Observatory, the effect of solar variability on the general circulation of the atmosphere and on observed weather is being studied.

- (f) Active.
- (a) HYDRAULICS OF SUB-CRITICAL FLOWS IN SMALL, ROUGH CHANNELS.
- (b) Colorado Agricultural Experiment Station; USDA Agricultural Research Service.
- (c) Norman A. Evans, Head, Department of Agricultural Engineering, Colorado State University.
- (d)
 - 1. Experimental and field investigation.
 - 2. Basic and applied, portions will be used for master's and doctoral theses.
- (e) The goal of this project is to develop design equations for furrow irrigation systems. The equations should relate furrow shape, slope, infiltration capacity and boundary roughness to non-erosive rates of flow. The first objective is to correlate random types of roughness with flow resistance in rigid, impermeable boundaries. The effect of infiltration through channel boundaries will then be considered. Natural soil

will be used in the laboratory to determine the sediment regimes which occur and to develop flow equations for these regimes. As a final phase, field experiments will be conducted to determine the validity of the laboratory results.

- (f) Active.
- (a) DRAINAGE DESIGN CRITERIA FOR IRRIGATED LANDS.
- (b) Colorado Agricultural Experiment Station.
- (c) Norman A. Evans, Head, Agricultural Engineering Department.
- (d) Applied.
- (e) Data on yields of tile drain systems in northern Colorado were collected, together with physical features and soil characteristics, from which a correlation analysis is made. The prediction equation so obtained is limited in application to the area under study.
- (f) Active. An extension of the project will be initiated in the future to study the hydraulics of the region near a tile drain, including the gravel filter.
- (g) A prediction equation based on degree of stratification has been found to be very reliable.

- (a) DEVELOPMENT OF AN ULTRASONIC STREAM BED ANALYZER.
- (b) Agricultural Research Service.
- (c) S. S. Karaki, Assistant Civil Engineer.
Earl Gray, Instructor, Electrical Engineering.
- (d) Applied.
- (e) The purpose of this research is to develop an electronic instrument to simultaneously measure the profile of the water surface and stream bed configuration under flow conditions in alluvial streams for both laboratory and field. Preliminary investigations indicate that sonic methods may be used to determine both air-water and water-solid interfaces, which enables measurement of water surface and stream bed profiles simultaneously. The instrument is expected to be fully transistorized and packaged for rugged use. The instrument will consist of a micro-second pulse, a broad-band receiver, a time measuring computer, a piezoelectric transducer, and a two-channel time-marked recorder. A cathode-ray oscilloscope will be optional.
- (f) Active.
- (g) The instrument is being designed for the proper transistor circuits. No tests have been undertaken.

- (a) PRESSURE DISTRIBUTION FOR TWO-PHASE FLOW IN A TWO-DIMENSIONAL POROUS MEDIA MODEL.

Cooperative project: Colorado Agricultural Experiment Station and Agricultural Research Service. See U.S. Department of Agriculture, Agricultural Research Service, page 40.

- (a) A STUDY OF TWO-PHASE, SINGLE COMPONENT FLOW IN A VENTURI.

- (b) NBS Cryogenic Engineering Lab (equipment) NSF Undergraduate Research Program.

- (c) R. V. Smith, Associate Professor of Mechanical Engineering.

- (d) Experimental; both basic and applied.

- (e) To analyze the flow process of steam and liquid H_2O from pressure and temperature surveys in the venturi. Vapor to liquid mass ratios, total mass flow and venturi geometry will be varied. Comparative runs for liquid H_2O -air systems will also be made (where no phase change is possible).

- (f) Currently active - most of the work is carried out in the summer months.

U. S. D. A.

Agricultural Research Service.

(2279) LABORATORY AND FIELD STUDY OF THE VORTEX TUBE SAND TRAP.

- (b) Agricultural Research Service, U. S. Department of Agriculture and Colorado Agricultural Experiment Station.
- (c) A. R. Robinson, Hydraulics Laboratory, Colorado State University, Fort Collins, Colorado.
- (d) Experimental; applied research.
- (e) The study is being made to develop generalized criteria for the design of the vortex tube sand trap. The sand trap will be used in irrigation and power canals for removal of bed load material.
- (f) Active.
- (g) Tests indicate that with the proper design, the vortex tube sand trap is very effective in the removal of bed load material for sizes greater than 0.3 mm. The efficiency of trapping varies with the velocity of flow across the tube and the size of material. High efficiencies can be maintained even though the amount of flow removed by the tube is reduces from 15 to 5 percent. Tubes of different shapes seem to operate equally well. However, the cross-sectional area and length of tube seem to be

critical points of design.

- (h) Publications now being prepared.
- (2901) LABORATORY STUDY OF GRAVEL FILTER DESIGN FOR IRRIGATION WELLS (Ref. No. 2901)
 - (b) Laboratory Project.
 - (c) E. Gordon Kruse, Agricultural Engineer, Hydraulics Laboratory, Colorado State University, Fort Collins, Colo.
 - (d) Experimental, applied.
 - (e) Laboratory studies were conducted to:
 1. Determine the relationship of pack-aquifer ratios and gradations to the amount of aquifer movement when wells are pumped,
 2. Develop generalized criteria for the selection and placement of gravel pack materials.
 - (f) Completed.
 - (g) The criteria for stability of uniform and non-uniform aquifers and gravel packs were determined by a series of tests in a radial flow model simulating a section of an irrigation well. The test results indicated:
 1. Less aquifer movement occurs with non-uniform gravel packs than with uniform gravel packs at the same pack-aquifer ratio.

2. At low pack-aquifer ratios, increasing aquifer uniformity decreases initial sand movement.
3. At high pack-aquifer ratios, increasing aquifer uniformity increases sand movement.
4. Reversing flow through the model to produce a surging effect reduced head loss at the pack-aquifer interface considerably.

Quantitative values of stable pack-aquifer ratios for uniform and non-uniform materials were determined.

- (h) "Selection of Gravel Packs for Wells in Unconsolidated aquifers, by E. Gordon Kruse, approved for publication as a technical Bulletin by Colorado State University.
- (2902) DEVELOPMENT AND IMPROVEMENT OF WATER MEASURING DEVICES.
- (b) Agricultural Research Service, U.S. Department of Agriculture and Colorado Agricultural Experiment Station.
 - (c) A. R. Robinson, Hydraulics Laboratory, Colorado State University, Fort Collins, Colorado.
 - (d) Experimental; applied research.
 - (e) The purpose of this project is to develop new water measuring devices and to improve existing ones for the measurement of irrigation water. Present phases are concerned with the development of trapezoidal measuring flumes and

the calibration of orifice plates for furrow flow measurements.

- (f) Active.
- (g) Preliminary tests on the trapezoidal flumes were previously reported. Much larger sizes have now been studied and have been found generally superior in operation to those with rectangular sections. The general shape of the trapezoidal flume is more easily adapted to the problem of open channel flow measurement.

Furrow orifices have been calibrated for a wide range of operating conditions. The sizes range from 3/4 to 4 inches in diameter.

- (h) "Trapezoidal flumes for open channel flow measurement", A. R. Robinson and A. R. Chamberlain. To be published in 1960 Transactions, American Society of Agricultural Engineers.

"Orifice plates for furrow flow measurements", by A. R. Robinson. Publication pending.

- (a) PRESSURE DISTRIBUTION FOR TWO-PHASE FLOW IN A TWO-DIMENSIONAL POROUS MEDIA MODEL.
- (b) Laboratory Project (ARS)
- (c) R. H. Brooks, Agricultural Engineer.

- (d) Experimental verification of the theoretical line where capillary pressure is equal to zero. i.e., $P_c = 0$.
- (e) A two dimensional porous media model 24 feet long, 4 feet in depth and 1 5/8 inches thick was set at an angle of 30° with the horizontal. The sand in the model consisted of three sands each increasing in permeability downstream. Water was caused to flow downslope under saturated condition through the less permeable sand. The purpose of the project is to determine the pressure distribution in the sands and the position of the line where the capillary pressure is equal to zero.
- (f) Active.