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Abstracts of the Papers Presented at the ASCE Hydraulics Division 17th Annual Specialty Conference

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ASCE HYDRAULICS DIVISION
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SIMULATION OF TIDAL HYDRAULICS IN LARGE SHALLOW EMBAYMENTS

Frank D. Masch,[1] William A. White,[2]
and Robert J. Brandes[3]

Fundamental to most water quality considerations in an estuary is a description of the hydrodynamic and transport characteristics of the system under the influence of various inputs and physical features. This paper is concerned primarily with a description of the tidal hydrodynamic characteristics in large shallow embayments. Working under the assumption of complete vertical mixing, a two-dimensional time dependent model is described which provides spatial and temporal variations of tidal amplitudes and vertically integrated tidal flows. The model accounts for various physiographic features such as dikes, spoil banks, reefs, channels, variable roughness, etc., found in the large shallow embayments typical of the Gulf Coast of the United States, and for variable inflows, tidal action, and other hydrologic characteristics of this area. The model further provides for the inclusion of wind stress and Coriolis forces. The basic responses from the model are the time histories of tidal amplitude and the velocities in each of two coordinate directions. From these data, phase relations and times of flood; ebb and slack tides are determined. Averaging of the velocities over a tidal period gives net flows which on integration with respect to time gives tidal excursions. Average velocities also provide average bay circulation. Finally, by scanning tidal amplitude variations, tidal prisms and low tide volumes are determined.

The model is designed to be responsive to the transport models necessary for water quality considerations, and the output from the model conditioned in the proper manner serves as direct input for descriptions of convective-dispersion phenomena. The interface between these two models is discussed, where appropriate, as the basic design of the tidal hydrodynamic model is dictated in part by the requirements of transport models.

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[1]Professor, Civil Engineering Department, University of Texas, Austin.

[2]Research Engineer, Civil Engineering Department, University of Texas, Austin.

[3]Research Engineer Civil Engineering Department, University of Texas, Austin.

SESSION 1C-2

TWO-DIMENSIONAL TIDAL COMPUTATIONS FOR POLLUTION STUDIES

J. J. Leendertse [1] *

A description is given of a mathematical modeling technique for tidal flow for use in the computation of transport, dispersion, and bio-chemical processes of waste discharge into well-mixed estuaries. The basis of computation is the vertically integrated equations of motion and continuity in a Eulerian system. The partial differential equations which include the effect of earth rotation and bottom roughness are approximated by difference equations. The equation of continuity is approximated by two sets of difference equations. The computations are two-dimensional in space.

An analytical investigation of the simplified difference equations indicates that the computation is unconditionally stable and that the discreteness of the time-space representation has no significant effects on the amplitude and propagation speed of the tide. An excellent agreement has been obtained between computed and measured data. The computational results are presented in graphical form, using a microfilm recorder, and can be displayed as an animated movie.

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[1]Engineering Science Department, the RAND Corporation, Santa Monica, California.

*Any views expressed in this paper are those of the author. They should not be interpreted as reflecting the views of the RAND Corporation or the official opinion or policy of any of its governmental or private research sponsors.

SESSION 1C-3

MATHEMATICAL MODELING OF TIDAL DISPERSION IN A NEUTRAL ESTUARY

Robert P. Shubinski [1]

Port Phillip Bay at Melbourne, Australia, has an area of some 600 square miles. There are no major inflows of fresh water into the bay, so it is either a neutral estuary or slightly negative, as a result of evaporation. The purpose of the study reported here was the evaluation of a number of sites for placement of a waste outfall.

Water circulation in the bay is two-dimensional. This was handled in a mathematical model by representing the bay as a network of channel elements for which relations of continuity, motion, and tidal transport and mixing were solved numerically.

The hydrodynamics portion of the model produced time-varying heads and flows as a result of tidal action, evaporation, and wind effects. With these unsteady flows and heads as inputs, the water quality model simulated the transport, distribution, and eventual loss, either through decay or entry to the ocean, of pollutants introduced at the various sites.

Interesting techniques described include the partial generation of data by the computer and the use of automatically plotted output. It is shown that rather low wind velocities produce substantial mixing in the bay which causes large convective currents. The net result is an assessment of the relative usefulness of several locations as outfall sites.

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[1]Chief, Computer Operations, Water Resources Engineers, Inc., Walnut Creek, California.

SESSION 1C-4

TIDAL MOTION IN IDEALIZED ESTUARIES

E. L. Bourodimos [1]

The interaction of long tidal waves with different estuary topographics is analyzed within the framework of the linearized small amplitude shallow wave theory.

The tidal wave motion was idealized by a train of harmonic monochromatic plane wave in steady state conditions.

Different geometries of estuaries are considered:

i) Combination of linear and nonlinear variation of depth and/or width.
ii) Submerged ridges and shelfs in the bottom of the estuary and along its course.

Expressions for the reflected and transmitted wave energy and variation of the wave characteristics are given in terms of transmission and reflection coefficients and amplification factors.

Numerical evaluation for a range of parameters of tidal wave and estuary geometry is under study.

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[1]Assistant Professor, Hydraulic Engineering, Ballantine Hydrodynamics Laboratory, College of Engineering, Rutgers the State University of New Jersey, New Brunswick, New Jersey.

SESSION 1C-5

ON THE OSCILLATIONS OF HARBORS OF ARBITRARY SHAPE TO PERIODIC AND DISPERSIVE WAVE EXCITATION

Li-San Hwang,[1] and B. LeMehaute[2]

An analytic method for solution of oscillations of a harbor of arbitrary shape and constant water depth is outlined. This method is based on the solution of an integral equation which is obtained from distribution of sources around the boundary. Advantages of this method are compared to other methods by application to the solution of Seiche problems. Finally, examples of practical calculation of the response of some existing harbors to periodic or dispersive wave excitation are presented.

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[1]Senior Scientist, Tetra Tech, Inc., Pasadena, California.

[2]Vice President, Tetra Tech, Inc., Pasadena, California.

SESSION 1D-1

PHYSIOGRAPHICALLY ADJUSTED PRECIPITATION-FREQUENCY MAPS FOR WESTERN UNITED STATES

John F. Miller,[1] Ralph H. Frederick,[2] and Robert J. Tracey[3]

Physiographically adjusted precipitation-frequency maps for 10 western states have been developed for the 6- and 24-hour durations for return periods from 2 to 100 years. In portions of western United States where snow contributes significantly to the series of extreme precipitation amounts, another set of precipitation-frequency maps were prepared for the May-October season, when practically all heavy precipitation is rain. Relationships between precipitation-frequency data for stations and topographic and climatic parameters were developed to aid in interpolating between stations in the preparation of generalized charts. Variation of precipitation-frequency values with elevation and exposure are also discussed.

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[1]Chief, Special Studies Branch, Office of Hydrology, ESSA, Weather Bureau, Silver Spring, Maryland.

[2]Special Studies Branch, Office of Hydrology, ESSA, Weather Bureau, Silver Spring, Maryland.

[3]Special Studies Branch, Office of Hydrology, ESSA, Weather Bureau, Silver Spring, Maryland.

SESSION 1D-2

WORLD WEATHER WATCH, PAST, PRESENT AND FUTURE

Gilbert Stegal[1]

The first part of this paper discusses the present status and future plans for the collection, quality control, real-time use, archiving, storage, retrieval and non-real-time use of meteorological data. Emphasis will be on data for non-real-time purposes. The second part of the paper discusses the archiving, storage, and retrieval of data at the National Weather Records Center at Asheville, North Carolina. This Center is considered a part of the World Data Center complex for data handling functions.

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[1]Chief, Climatic Operations Branch, ESSA National Weather Records Center, Asheville, North Carolina.

SESSION 1D-3

THE WATER TEMPERATURE REGIME OF FULLY-MIXED STREAMS

Walter O. Wunderlich[1] and Rex A. Elder[2]

The water temperature regime of a stream over the yearly cycle conditions its quality as a habitat for aquatic life and is important in water use considerations for municipal and industrial purposes. The basic physical laws governing the temperature regime of a fully-mixed stream will be derived as functions of its geometric, hydraulic, and meteorological characteristics. These analytical relationships are then used in the prediction of alterations of the original temperature regime resulting from various types of artificial interference, such as creation of an impoundment or hot water releases from steam plants.

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[1]Research Engineer, TVA Engineering Laboratory, Norris, Tennessee.

[2]Director, TVA Engineering Laboratory, Norris, Tennessee.

SESSION 1D-4

A DISTRIBUTED LINEAR MODEL OF SURFACE RUNOFF

Peter S. Eagleson[1] and William O. Maddaus[2]

The kinematic wave approach to surface water is used as a nonlinear standard for the development of a linear, but distributed model of catchment behavior. The basic element consists of a parallel array of n "Nash chains" of order m = 1 through m = n, each containing a linear channel of time constant mk. (A Nash chain of order m is a cascade of m linear reservoirs, each of time constant k.) Allowance for the effect of a principal nonlinearity is acomplished by selection of an appropriate pulse magnitude for convolution purposes.

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[1]Professor of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

[2]Research Assistant, Massachusetts Institute of Technology, Cambridge, Massachusetts.

SESSION 1D-5

A HYDROLOGICAL WATER RESOURCE SYSTEM MODELING TECHNIQUE

L. G. Hulman [1] and D. K. Erickson [2]

The record Northeastern United States drought of the 1960's has required a detailed reappraisal of water resource systems previously proposed in the affected areas. The ability to judge the competency of proposed engineering structures in the Delaware basin was hampered by the diversity of projects, the political constraints on existing projects in the upper portion of the basin and the numerous alternative demands on available surface water. To facilitate analysis of the effects of the drought, a mathematical modeling technique was developed to allow simulation of the hydrological properties of the lower Delaware basin and proposed engineering structures. The technique and its application to the Delaware are discussed. The results of the reappraisal of project yields utilizing the model are presented and compared with pre-1960 yield estimates.

[1] Hydraulic Engineer, The Hydrologic Engineering Center, Corps of Engineers, Davis, California.

[2] Hydraulic Engineer, U.S. Army Engineer District, Philadelphia, Pennsylvania.

SESSION 1E-1

PROGRESS REPORT - PROBLEM-ORIENTED LANGUAGES IN HYDROLOGY

George Bugliarello [1]

The essential technical characteristics and mode of operation of problem-oriented languages and the tasks involved in constructing problem-oriented languages for hydrology and hydraulic engineering are reviewed.

Current conflicts in philosophy concerning the development and use of a problem-oriented language for hydraulic engineering are highlighted. These include the issue of a library of sub-routines or procedures versus a direct problem-oriented language system, the dimensions of the building blocks in the library of the problem-oriented language (small and flexible versus large and more specialized), the language base of the system (e.g. ALGOL versus FORTRAN), the type of users (in terms of programming skills and facilities) to whom the system is addressed, the need for a central repository and its operating characteristics.

The policy implications arising from the various possibilities are discussed as a stimulus for feedback from the audience.

[1] Professor, Civil Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania.

TECHNIQUES OF MEASURING FLOW IN OPEN CHANNELS

Harry H. Barnes, Jr.,[1] L.A. Martens,[2] H. O. Wires,[3]
Jacob Davidian,[4] G. F. Smoot,[5] F. A. Kilpatrick,[6] and G. L. Bodhaine[7]

This paper will present various techniques which have been developed and employed by the U.S. Geological Survey for measuring and gaging discharge in open channels. The paper will cover four major areas, as follows:

1. A Streamflow Monitoring System for Variable Control Structures by H. H. Barnes, Jr., L. A. Martens, and H. O. Wires

An electrical-servo balancing system has been developed by the Geological Survey for monitoring streamflow parameters at variable control structures. The system is particularly suited for gaging streams where navigation is maintained by means of lock and dam structures. The relationships between stage, discharge, and water-surface slope resulting from such regulation are too insensitive in the low-flow range for the computation of reliable discharge record by conventional stream gaging methods. The control structure offers the advantage of a unique discharge relation for a given control operation in the flow range where definition is needed.

The monitoring system has the capability to accurately measure and record the various flow parameters such as the vertical position of control gates, turbine pressure differentials, lockages, and water stages. Individual parameter measurements are programmed to be recorded in sequential order on one or more digital recorders. The digital recorder tapes are processed into discharge record by a high speed computer.

The establishment of this monitoring system consists of three parts: first, the installation and calibration of instrumentation; second, the field procedure to determine discharge coefficients for the movable gates and turbines; and third, the development of a model to compute discharge for the various flow conditions expected. This paper describes the recent establishment of a gaging station on the Ohio River at Greenup Lock and Dam utilizing the new monitoring system.

2. A Comprehensive Evaluation of Dye-Dilution Discharge Measurement Applications by F. A. Kilpatrick

The advent of stable fluorescent dyes and accurate means of measuring them in low concentrations has increased the interest in dilution gaging.

A variety of dye-injection methods has been tested including slug, constant rate, and line. Many sampling techniques have been tested, including grab sampling, velocity-weighted sampling, integrated-pump sampling, and continuous fluorometer flow-through sampling.

Dilution gaging has proven successful in measuring flows of turbulent mountain streams, unstable sand-channel streams, and flow beneath ice. The method has proven particularly suited to measuring flows in canals, flumes, pipes, and other manmade structures. Its application in measuring sewage and other debris-laden flow has proven most useful.

The successful measurement of unsteady flow by the method has pointed the way to automatic and complete gaging of storm-runoff hydrographs. Preliminary tests of a complete streamflow gaging station with automatic dye injection and sampling have proven encouraging.

Other promising applications are the rating of turbines, the measurement of flow through sinkholes, and the measurement of contributing aquifer flows in a ground-water well.

3. Discharge Measurements in Large Rivers by the Moving-Boat Method by Jacob Davidian and G. F. Smoot

The moving-boat method of measuring discharge was developed for use in large streams where conventional methods are impractical and involve costly and tedious procedures. It is particularly suited to measurements in estuaries, where continuous discharge hydrographs over entire tidal cycles are required. During the traverse of a boat across a stream, a sonic sounder records the geometry of the cross section, and a continuously operating current meter senses the combined stream and boat velocities. These data are converted to discharge for the cross section quickly, efficiently, and inexpensively.

In this paper, measurements made by the method are compared with measurements made or computed by more conventional means. The consistency and the accuracy experienced are shown both under steady-flow conditions in large rivers, and under unsteady-flow conditions in estuaries.

4. Vertical-Velocity Profiles in a Deep River by G. L. Bodhaine

Vertical-velocity profiles in the Columbia River and changes that occur in mean velocity of a profile over a period of time were used to evaluate the relative accuracy of standard methods of determining velocity and to determine the length of time needed to accurately measure the mean velocity in a specific profile. The variation in velocity with respect to time and depth was studied by comparing one-minute vertical-velocity curves defined for recorded simultaneous velocity data from 10 Price current meters. These meters were suspended at equal-depth intervals in a vertical section and operated continuously for 66 minutes.

The lower part of the vertical-velocity curve follows a power function. The vertical-velocity curves show an increase in velocity throughout their entire length from bottom to top. The shape of the curve changes constantly, and one-minute velocities may vary as much as 15 percent from one-hour mean. The .2-.8 depth

method of measuring mean velocity is valid. About four minutes are required to obtain an accurate determination of velocity at a point.

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[1] U.S. Geological Survey, Washington, D.C.

[2] U.S. Geological Survey, Washington, D.C.

[3] U.S. Geological Survey, Columbus, Ohio.

[4] U.S. Geological Survey, Washington, D.C.

[5] U.S. Geological Survey, Washington, D.C.

[6] U.S. Geological Survey, Washington, D.C.

[7] U.S. Geological Survey, Portland, Oregon.

SESSION 2A-2

MEASURING FLUMES--PAST AND PRESENT

A. R. Robinson [1]

Widespread use is made of Parshall measuring flumes throughout the United States and in other parts of the world. Many modifications have been made to standard Parshall flumes and in some instances these modifications have been made without regard to resulting changes in operation and calibrations. In recent years, trapezoidal flumes of various sizes and geometries have been developed and are in limited use. There have been a multitude of designs proposed and claims made as to the superiority of each design.

This paper reviews: some of the changes which have been made to Parshall flumes; the effect of these changes based on recent work by the author and others; research on trapezoidal flumes; and design and operation of the various structures; and the problems associated with design changes and modifications. Unification and standards for designs and operation are urged.

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[1] Research Agricultural Engineer and Director, U.S. Department of Agriculture, Agricultural Research Service Sedimentation Research Laboratory, Oxford, Mississippi.

THE VERTICAL SLOT

H. M. Hill,[1] T. E. Unny,[2] and Frank Ford[3]

An open channel flow measurement structure has been investigated with the objective of developing a low cost accurate structure for water with considerable debris. The vertical slots investigated were placed in a rectangular laboratory channel. Upstream wingwalls were placed as 45 degree angles. The floor elevation at the structure is the same as the rest of the channel. The discharge coefficients for width of opening to width of channel of 0.25, 0.50, and 0.75 were correlated with flow parameters. Limit-effects of abutment thickness, drowning, and viscosity on the discharge coefficient were investigated.

[1]Associate Professor, University of Waterloo, Ontario, Canada.

[2]Associate Professor, University of Waterloo, Ontario, Canada.

[3]Design Approvals Engineer, Ontario Water Resources Commission.

OPTIMAL DESIGN OF SUB-SURFACE LOW FLOW AUGMENTATION STORAGE FACILITIES BY HYBRID COMPUTER

J. T. Gormley,[1] H. J. Day,[2] and R. M. Shane[3]

The optimal use of ground water as a low flow augmentation source to maintain stream water quality standards is the subject of this paper. Techniques for performing a feasibility investigation using a hybrid computer as the primary computational tool are presented. A mathematical model is described which includes temporal effects of the aquifer piezometric head, random generation of streamflow and overall system performance indicators.

The analog segment of the hybrid allows for virtually instantaneous solution of the systems of differential equations describing changes in the ground water table over time. The digital segment of the hybrid allows for the statistical analyses of available data and analog-computer information and the generation of stochastic data.

Cost and performance information are presented for the use of ground water to maintain water quality. The engineering economics and geology related to the general problem are discussed and related to a specific study area--the valley of the Great Miami River in Southwestern Ohio.

The potential desirable use of these techniques and computational aids for comprehensive river basin planning, including conjunctive use of ground and surface water as an alternative, are discussed in the conclusion of the paper.

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[1]Research Assistant, Department of Civil Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania.

[2]Associate Professor, Department of Civil Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania.

[3]Assistant Professor, Department of Civil Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania.

SESSION 2B-2

OPTIMIZING CONJUNCTIVE USE OF SURFACE AND GROUNDWATER--BY LINEAR PROGRAMMING

Calvin G. Clyde [1] and James H. Milligan [2]

Mathematical models for groundwater and surface-water systems are formulated and solved on a digital computer using linear programming for optimizing the water use of the system. Post-optimal analysis, including sensitivity analysis of objective function coefficients and right-hand side terms, is also applied to the models.

The models which are developed include a general deterministic model, a general stochastic model in which hydrologic inputs are allowed to be probabilistic, and a model of a particular hydrologic basin in Central Utah.

The advantages of linear programming analysis are demonstrated by the computer outputs which can be obtained by this method of optimization. The method is shown to be effective as a guide to optimal water resources systems design and planning.

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[1]Assistant Director, Utah Water Research Laboratory, Utah State University, Logan, Utah.

[2]Research Engineer, Utah Water Research Laboratory, Utah State University, Logan, Utah.

OPTIMIZING CONJUNCTIVE USE OF SURFACE AND GROUND WATER–BY DYNAMIC PROGRAMMING

Gert Aron [1] and Verne H. Scott [2]

The objective of most present-day projects in the systems optimization field is to increase the scale of complexity of the problems to which operational mathematics can be applied.

Most mathematical optimization methods, when applied to nonlinear systems, break down if the number of variables describing the state of the many components of a system and the number of decision variables which modify the state become excessive. Most realistic water resources systems have an excessive number of state and decision variables.

In this study a subdivision of a complex system into several smaller and simpler subsystems is suggested. Operation of these subsystems is optimized independently, even if this procedure is not always fully justifiable, resulting in a relatively small number of lumped state and decision variables. These are then dealt with conjunctively in an effort to optimize the combined operation of these subsystems. Several subsidiary methods to speed up the process of scanning for the peaks in empirically functional relationships are also suggested.

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[1]Assistant Professor, Civil Engineering Department, Pennsylvania State University, University Park.

[2]Professor of Water Science and Civil Engineering, Department of Water Science and Engineering, University of California, Davis.

COMPUTER SIMULATION OF UNSTEADY GROUND WATER FLOW

G. M. Karadi, [1] R. J. Krizek, [2] and Hameed Elnaggar [3]

The theoretical problems of unsteady ground water flow, with evaporation (or infiltration), are discussed. A method is proposed for computer simulation based on matrix mathematics. It has the advantages of being able to handle complicated initial and boundary conditions, including sloping impermeable layer, and to consider step by step the non-linearity of the governing differential equations. The results calculated by this technique, when compared with experimental data obtained from a

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[1]Assistant Professor, Civil Engineering Department, Pennsylvania State University, University Park.

[2]Professor of Water Science and Civil Engineering, Department of Water Science and Engineering, University of California, Davis.

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new type of model the so-called "groove-model," exhibit a better agreement than other methods based on linearization technique.

[1]Associate Professor, Department of Mechanics, University of Wisconsin, Milwaukee.

[2]Associate Professor, Department of Civil Engineering, Northwestern University, Chicago, Illinois.

[3]Graduate Student, Department of Civil Engineering, Northwestern University, Chicago, Illinois.

SESSION 2B-5

TWO DIMENSIONAL PARTIALLY SATURATED STEADY FLOW IN SOILS

Roland W. Jeppson [1]

The mathematical model describing Darcian flow of water through soils approximates actual occurrences more closely when it permits some regions of the flow to be partially saturated. The formulation of the partially saturated flow problem as proposed in this paper, in contrast to other work in this field, considers the cartesian coordinates x and y as the dependent variables and the total fluid head and the two-dimensional stream function as the independent variables (i.e. the problem is solved for x and y in the plane defined by the potential function and the stream function). A generally accepted relationship between effective permeability and capillary pressure is utilized in obtaining the partial differential equation (nonlinear) which describes the flow. The resulting boundary value problem is solved by finite differences.

The above approach has been applied to the problem of seepage from a canal to a water table, and a computer program (FORTRAN IV) has been written to carry out the computations. Sample solutions are presented for flow through homogeneous and heterogeneous soils, and a comparison is made between one of these solutions and a similar solution based on the more usual assumption that a sharp line of seepage separates regions of completely saturated flow from regions through which no flow occurs. The comparison indicates that solutions based on the usual assumption underestimate the quantity of seepage loss by a considerable amount particularly if the soil is fine grained. Furthermore, much more spreading is indicated by the partially saturated solution, with a large area beneath the canal only partially saturated.

[1]Associate Professor of Civil Engineering, Utah Water Research Laboratory, Utah State University, Logan, Utah.

DESIGN APPROACHES FOR SCOUR AT WATERWAY CROSSINGS PANEL DISCUSSION

L. A. Herr,[1] C. R. Neill,[2] E. M. Laursen,[3]
S. H. Shen,[4] Verne Schneider,[5] and Mainard Wacker[6]

Each panel member will present a short talk concerning the nature of scour, the magnitude of the problem, the design of waterway crossings to decrease scour, and the prediction of the depth of scour. After this presentation, the panel will discuss each other's point of view with short criticisms, short rebuttals, and a general examination of the problem. At this time there will be a general floor discussion of the scour problem at waterway crossings.

[1]Chief, Hydraulics Branch, U.S. Department of Transportation, Washington, D. C.

[2]Hydraulic Engineer, Highway Division, Research Council of Alberta, Edmonton, Alberta, Canada.

[3]Consultant, Hydraulics and Hydrology Specialty Group, U.S. Department of Transportation, Washington, D.C.

[4]Professor, Civil Engineering Department, Colorado State University, Ft. Collins, Colorado.

[5]Hydraulic Engineer, U.S. Geological Survey, Ft. Collins, Colorado

[6]Hydraulic Staff Engineer, Wyoming Highway Department, Cheyenne, Wyoming.

TIBER DAM AUXILIARY OUTLET WORKS

M. A. Jabara[1] and W. E. Wagner[2]

A supplemental outlet capacity for Tiber Dam became necessary when the foundation for the spillway irreparably failed. In progress is the construction of a cofferdam across the spillway inlet channel and modification of an existing incomplete high level canal outlet works to provide sufficient additional capacity,

with abandoned storage allocations, to accommodate the inflow design flood. The modified outlet facility is designated as the auxiliary outlet works. It branches downward from the invert of the existing tunnel, then directs the flows through a vertical elbow in a normal direction presenting unusual flow characteristics. Hydraulic model studies were conducted to determine the behavior of flows as they are deflected down to the branch inlet and elbow, and through the remainder of the system.

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[1] Supervising Civil Engineers, U.S. Bureau of Reclamation, Denver, Colorado.

[2] Head, Structures and Equipment Section, U.S. Bureau of Reclamation, Denver, Colorado.

SESSION 2D-2

CONTROL FEATURES OF THE FOOTHILL FEEDER SYSTEM

David S. Louie [1] and George F. Horowitz [2]

The paper gives a brief description of the Metropolitan Water District of Southern California's plans for expansion of its existing distribution system to handle the additional water which will soon be delivered to the Southern California Coastal Plain by the California State Water Project. The backbone of this development is the Foothill Feeder. The reasons for the selection of hydraulic gate structures to control the flows will be given. The design of certain, unusual gate control structures will be reviewed. The hydraulic model studies of the structure, gates, and the hydro-elastic vibration studies of the latter will be presented. Motion pictures of the model study will be shown.

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[1] Chief Hydraulic Engineer, Harza Engineering Company, Chicago, Illinois.

[2] Senior Civil Engineer, Metropolitan Water District of Southern California, Los Angeles, California.

MODEL STUDIES ON TWO HYDRAULIC STRUCTURES

W. G. Godden [1]

The results of model tests on two different hydraulic structures will be presented:

1. **Stresses in Wye-Junctions Subjected to Internal Pressure**

The prototype structure is a 12'-6" diameter pipe bifurcation subjected to a 1000 psi pressure. A precise 1/15th scale model has been machined out of plastic to simulate the elastic response of the system, and to check on the accuracy of finite-element procedures currently being developed for computing stresses in structural systems with complex geometry.

Measured and calculated stresses will be presented, together with the influence of certain geometrical changes in the design on the overall response of the system.

2. **Dynamic Response of a High Intake Tower**

A hydro-elastic model of a high intake tower has been constructed for the purpose of measuring the dynamic response of the structure to various hydraulic flow conditions. Specifically the possibility of a hydro-elastic resonance is under study.

The prototype structure is a 212 ft. high, 32 ft. diameter free-standing reinforced concrete intake tower. Thirty-six butterfly valves are arranged over the height of the tower so that water can be drawn off at any desired level. The model is to a scale of 1/30 and is made of plastic. In addition to reproducing the necessary flow conditions, the model also reproduces the structural stiffness and mass of the tower so that structural dynamic properties are simulated.

The dynamic response of the tower is recorded from 6 accelerometers. This data is fed either to a storage oscilloscope via a spectral analyzer where the spectral response is photographed, or to magnetic tape for subsequent reduction by computer.

The following studies are being made: (a) The effect of the coupled mass of water on the natural frequencies of the tower; (b) the effect of water on the total structural damping of the system; (c) spectral response of the tower to a wide range of flow conditions; (d) the search for a possible hydro-elastic resonance in the system.

Slides of the models and response data will be presented in both cases.

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[1] Professor of Civil Engineering, University of California, Berkeley.

DRAG COEFFICIENTS FOR STILLING BASIN BAFFLES

David R. Basco [1]

Baffle blocks improve the performance of hydraulic jumps used as energy dissipators. A knowledge of drag coefficients for practical baffle geometries would permit rational stilling basin designs without continued recourse to model tests.

The results of an experimental study in which drag forces were measured with load cells for a wide variety of baffle geometries and locations are presented. Using the measured drag forces the drag coefficients have been calculated for all tests. It is well known that appurtenances placed in a hydraulic jump greatly affect the performance of the jump. The following performance criteria is of greatest interest:

1. Length of jump
2. Tailwater depth
3. Energy loss
4. Downstream wave heights
5. Bottom velocities
6. Cavitation potential on blocks

Experimental measurements have been made to evaluate each of the above performance criteria for all those geometries tested over a wide range of jump Froude numbers. An attempt is then made to use the drag coefficient as the correlating parameter with the above mentioned performance criteria. Of course, forced jump, sequent depths can be calculated directly using the linear momentum equation.

Because of the large number of geometrical variables involved, a special geometry parameter combining the block size and location has also been developed and its use in correlating the data will be explained.

Several unique, yet economically feasible block shapes were investigated and the results of their performance will be discussed.

[1]Research Hydraulic Engineer, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

SESSION 2D-5

STATUS REPORT: PREPARATION OF REGISTRY ON SELECTIVE WITHDRAWAL WORKS IN THE UNITED STATES

Ronald E. Nece [1]

The Task Committee on Outlet Works is preparing a register of projects in the United States in which provisions have been made for selective withdrawal of water from predetermined elevations in reservoirs. The register is being compiled from returns to questionnaires distributed by the committee. Available data will be summarized briefly in the status report.

[1]Professor, Civil Engineering Department, University of Washington, Seattle.

SESSION 2E-1

MULTIPLE-PURPOSE OPERATION OF RESERVOIRS FOR IRRIGATION AND FLOOD CONTROL

Harold D. Hafterson [1]

Imagine the owners of irrigation storage dumping water from their reservoirs as fast as practicable throughout a 3- or 4-month period and winding up with empty reservoirs at the beginning of the irrigation season. This seeming anachronism is being enacted in many locations of the Pacific Northwest, where it has been found that ability to forecast snow-flood runoff volume can be depended upon as a basis for joint-use of reservoir space for flood control and irrigation. Development of rule curves for control of winter rain floods and of flood storage reservation curves to be used in combination with forecasts of anticipated snowmelt flood volumes permits multiple use of the total active capacity of many reservoirs where it is impractical to provide exclusive space for each purpose. Millions of dollars of potential flood damage has been prevented by changing operations of single-purpose reservoirs to fuller multiple-purpose use.

[1]Chief, Hydraulics Branch, Project Planning, U.S. Bureau of Reclamation, Boise, Idaho.

SESSION 2E-2

UNIT HYDROGRAPHS AND WATERCOURSE ROUGHNESS

W. L. D. Bottorf [1] and A. G. Cudworth, Jr. [2]

A re-examination of some 75 unit hydrograph studies made by the Corps of Engineers since 1941 for California and Arizona stream basins of varying area, shape, and slope, and with watercourses of different hydraulic roughness characteristics indicates that lag times are greatly affected by the roughness of the principal channels. The unit hydrograph studies were based on hydrologic data of considerable variety: the drainage basins ranged in size from a fraction to about a thousand square miles, and in type from rugged mountain wilderness to flat urban terrain; the floods were due either to general orographic rainfall or to local convective rainfall, and the unit periods ranged from 10 minutes to 2 hours. Lag times are now shown to be related to a conventional basin shape factor ($LL_{ca}/S^{½}$) and to watercourse roughness expressed in terms of Manning's "n," which appears to range between about 0.015 and 0.150. A procedure currently employed for utilizing the roughness parameter for deriving synthetic unit hydrographs and for estimating the effect of watershed changes, including urban development is described. A discussion of expected variations of roughness in floods of different magnitudes is included. While full mathematical precision in the analyses and application is not expected, results within normally accepted tolerances are readily obtainable, and the procedure is believed to hold much promise for future refinement.

[1] Chief, South Pacific Division, Corps of Engineers, San Francisco, California.

[2] Hydraulic Engineer, South Pacific Division, Corps of Engineers, San Francisco, California.

SESSION 2E-3

OPERATING PLAN FOR FLOOD CONTROL REGULATION BY COLUMBIA TREATY PROJECTS

Mark L. Nelson [1] and David M. Rockwood [2]

This paper describes the method of operation for flood regulation of three storage reservoirs in the Columbia River Basin in Canada (Duncan, Arrow, and Mica Projects), and Libby Project in the United States, which are now under construction or completed under terms of the treaty for Development of the Water Resources of

the Columbia between the United States and Canada. The Columbia River, which is primarily snow-fed, is characterized by an annual flood period of two to three months, with peak flows occurring in May or June. Flood regulation is based on utilization of forecasts of runoff, both for seasonal runoff volume and day-to-day rate-of-flow, whereby optimum use of storage space is made for flood regulation and meeting all other project requirements on a multiple-use basis. The flood regulation is to be achieved primarily for the protection of the flood plain along the Lower Columbia River below Bonneville Dam, but protection is also afforded to upstream local flood areas in both Canada and the United States. The operation of Canadian Treaty storage is integrated into the overall flood regulation plan for the Columbia River on a system basis. The plan has been tested on 30 historical years of record, 1920-1958, as well as major floods of record in other periods. Flood regulation studies were performed by use of the SSARR (Streamflow Synthesis and Reservoir Regulation) computer program. The results of these studies are summarized.

[1] Chief, Water Control Branch, U.S. Army Engineer Division, North Pacific, Portland, Oregon.

[2] Chief, Hydrology and Hydraulics Section, U.S. Army Engineer Division, North Pacific, Portland, Oregon.

SESSION 2E-4

STATE ACTIVITIES IN FLOOD PLAIN IDENTIFICATION AND MANAGEMENT

Donel J. Lane [1]

This paper describes selected state activities in the field of flood plain identification and land-use regulations as a supplement or alternate to mitigation of flood damages by structures. As a prelude it briefly recounts some of the history of attempts to manage and control waters by structures and the local and state response thereto. It attempts to analyze and present viewpoints of some state officials as to the effectiveness of flood plain identification studies by federal agencies for the purpose of providing basic information that can be translated into legally enforceable land-use regulations.

It reviews some of the administrative problems of land-use regulations and touches upon some of the legal ramifications.

[1] Director, State Water Resources Board, Salem, Oregon.

STOCHASTIC STREAMFLOW SIMULATION ON THE ANALOG COMPUTER

Rafael G. Quimpo [1]

An important step in streamflow simulation is the synthesis of deterministic and stochastic components of the runoff process. Although analog computers have been used mainly in the simulation of deterministic systems, if they can be adapted to include stochastic capabilities, their use in streamflow synthesis would be of tremendous advantage in engineering planning and design. This advantage lies in the operational flexibility, low cost of operation, and susceptibility to fast sensitivity analysis of analog models—features which are highly desirable in operation studies involving dynamic decision-making.

The coupling of an analog computer with a random-noise generator to provide a source of deterministic and stochastic variables is outlined. Schematics of generating streamflow traces of progressively increasing complexity in statistical structure are exhibited. An exponential time-lag approximation is used to incorporate persistence or autocorrelation of the stochastic component. Preliminary results for a simple Markov model of constant variance are presented. It is shown that the transformation of non-normally distributed variables and modifications to allow for time-varying variance and skewness can be made. Future possibilities include the linkage of the streamflow generator with other sub-systems in an operation study, or use in a hybrid computer system. Applications in low-flow augmentation and stream-pollution research are suggested.

[1]Assistant Professor, Civil Engineering Department, University of Pittsburgh, Pittsburgh, Pennsylvania.

SUPERPOSITION OF WEEKLY AND DAILY FLOWS UPON MONTHLY FLOWS IN HYDROLOGIC SIMULATION

David H. Moreau [1]

The response of water resource systems can be defined by flows that are averaged over hourly, daily, weekly, monthly, seasonal, or annual time intervals depending upon the purpose that is served by a particular system. For analyses where several objectives are considered simultaneously, e.g., reservoir systems that are used for flood control, water supply, and quality control in downstream stretches of a basin, the relevant averaging interval may vary from one period of time to another.

Simulation of all hydrologic events that are averaged over the shortest time interval generates a large amount of irrelevant sequences at considerable expense and with attendant problems of storage. Significant economies of computation and storage can be achieved by adopting a basic averaging interval, say one month, upon which flows of shorter duration can be superimposed as required or as indicated by averages over the basic averaging interval. In this discussion, relationships among flows of various durations will be examined, previous studies will be discussed, and two new approaches for the superposition of flows will be presented.

[1]Assistant Professor of Planning and Environmental Sciences and Engineering, Department of City and Regional Planning, University of North Carolina, Chapel Hill, North Carolina.

DECISION CRITERIA FOR USING STOCHASTIC HYDROLOGY

G. K. Young,[1] G. T. Orlob,[2] and L. A. Roesner[3]

A decision-theoretic plan for providing insight into questions of interest to the system planner about to embark on a study which uses stochastic or operational hydrology is presented. The plan considers and integrates three broad areas which are: 1) the collection, interpretation, and adjustment of the data bank which is required to initiate stochastic modeling, 2)the investigation of existing, and development of new, stochastic hydrology models, and 3) the construction of a unique water resource simulation procedure to serve as the vehicle for which the importance of the other necessary tasks can be determined. Key features of the plan are dissected and their probable impact on design decision is estimated. The overall plan has component tasks which correspond directly to the design steps of the system planner.

[1]Senior Engineer, Water Resources Engineers, Inc., Walnut Creek, California.

[2]President, Water Resources Engineers, Inc., Walnut Creek, California.

[3]Associate Engineer, Water Resources Engineers, Inc., Walnut Creek, California.

STORAGE REQUIREMENTS DETERMINED BY ANALYZING FREQUENCY DISTRIBUTIONS OF RUNNING AVERAGES OF STREAMFLOW OVER EXTENDED TIME PERIODS

Roland W. Jeppson [1]

One disadvantage of the mass-curve (or Rippl diagram) approach for determining storage requirements is that it is difficult to assign recurrence intervals or probabilities of occurrence to the most severe shortage experienced during the period of the record. A method for obtaining the storage requirements not only related to the probability of occurrence (recurrence interval or return period) but also related to the probable length of the time the water must be stored in the reservoir, and the level of demand or use rate of the water, is by the use of what will be termed "Frequency Mass-Curve Analyses." Having information on this basis makes possible more realistic designs and economic analyses based on desired levels of risk.

A frequency mass-curve, for any given probability of occurrence, results from plotting, for any given probability of occurrence, the expected values of accumulated volumes of runoff occurring during each of many sequences of consecutive months (through several years) against the period in months. Separate frequency mass-curves result for each probability of occurrence. The frequency mass-curves for high probabilities of occurrence which are associated with low flows result in lines concaved upward, whereas the frequency mass-curves drawn for low probabilities are concave downward. Similar to the usual mass-curve the slope of the frequency mass-curve at any time represents the flowrate, and the difference between the ordinate of an accumulated demand curve imposed on the graph and the ordinate of the frequency mass-curve represents the storage needed to satisfy that demand, or in the case of negative differences the volumes of water available for storage.

The approach of determining storage requirements by using frequency mass-curve analyses has been tested by writing a FORTRAN program to carry out the needed computation.

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[1] Associate Professor of Civil Engineering, Utah Water Research Laboratory, Logan, Utah.

THE USE OF STREAMFLOW SYNTHESIS ROUTINES TO DETERMINE MULTI-RESERVOIR OPERATING RULES

Theodore G. Roefs [1]

In his dissertation at Harvard, "Finding Reservoir Operating Rules," G. K. Young explored the use of an analysis process employing stochastic streamflow synthesis routines, dynamic programming, and regression analysis for the purpose of finding single-reservoir operating rules. The present work is concerned with extending this philosophy of analysis to multi-reservoir problems. Two research problems require solution in order to achieve this objective. The first is the definition of computationally feasible deterministic optimization algorithm which realistically represents a multi-reservoir system. The second is the determination of the form and relevant independent and dependent variables in the regression relationships to be used.

In general the analysis process involves two sets of data and an operator. A set of possible future streamflow volumes is one set of data. The operator, a deterministic optimization routine, operates on this data to produce a set of reservoir release and volume data. The process would be repeated several times. The regression analysis would operate on both sets of data.

[1]Staff Member, Washington Scientific Center, IBM Corporation, Wheaton, Maryland.

STATISTICAL DESIGN OF DATA COLLECTION SYSTEMS

N. C. Matalas [1]

Sequences of hydrologic events collected at a set of gaging stations are to some extent cross-correlated so that the information contained in the sequences is to some degree redundant. The cross-correlation structure is the basis for assessing an existing data collection system to determine if the system should be expanded or contracted. This determination is carried out with the following constraints imposed on the system: 1) budgetary, 2) accuracy, and 3) risk in detecting change in the hydrologic environment.

The budgetary constraint refers to the cost of data collection, and the accuracy constraint refers to how well statistical parameters such as the mean and variance can be estimated from the observed sequences. The risk constraint is imposed to determine the number of stations that must be maintained to monitor

changes that are likely to occur in the future. This constraint requires: 1) postulating a model for the areal distribution of change, 2) defining a change, and 3) relating the probability of detection of a change to the correlation structure in the system.

[1] Research Hydraulic Engineer, U.S. Geological Survey, Washington, D.C.

SESSION 2F-7

AN OBJECTIVE DETERMINATION OF SAFETY FACTOR IN RESERVOIR DESIGN

E. R. Close, [1] D. R. Dawdy, [2] and L. R. Beard [3]

Objective criteria for determining hydrologic safety factor for reservoir design are developed for streamflow sample sizes of 10, 25, 50, and 100 years. For the smaller sample sizes, the index of allowable shortages, for which average net benefits are maximum, is also smaller. This reduction in the index of allowable shortages results in an increase in the average reservoir size needed to offset the effects of sampling error. Thus, by varying the index of allowable shortages on the basis of hydrologic record length, safety factors may be determined.

[1] Research Hydrologist, Hydrologic Systems Laboratory, U.S. Geological Survey, Menlo Park, California.

[2] Research Hydrologist, Hydrologic Systems Laboratory, U.S. Geological Survey, Menlo Park, California.

[3] Director, The Hydrologic Engineering Center, Corps of Engineers, Davis, California.

SESSION 2F-8

STRUCTURE OF HYDROLOGIC TIME SERIES

V. Yevjevich [1]

A review of the current research on stochastic processes in hydrology in the graduate research program at Colorado State University will be given. This will include techniques being used for the analyses of continuous and discrete hydrological time series and both non-stationary and stationary time series. The

studies of space dependence among hydrologic variables will be outlined. The investigation of runs, theory of surplus, deficit and range, and other techniques which are being studied for a potential application to hydrology will be briefly discussed. The lines followed in the theoretical and experimental investigation of storage problems, and of water systems in general, will be described as of the status by the summer of 1969.

[1]Professor of Civil Engineering, Colorado State University, Fort Collins, Colorado.

ANALYSIS AND MODELING OF THE STOCHASTIC PROPERTIES OF HYDROLOGIC DATA IN THE TUCSON BASIN (ARIZONA)

ChesterC. Kisiel [1]

In this paper a progress report is presented on the analysis and modeling of the stochastic properties of precipitation, streamflow, and groundwater (including natural recharge) phenomena in the arid land and metropolitan watersheds of Tucson, Arizona. The effort is part of two research projects involving, (1) an operations research study of water resource development and management in the region, and (2) a study of the efficiency of data collection systems in hydrology and water resources for prediction and control. The data analysis is being pursued in the context of modern methods of signal or time series analysis and multivariate analysis. The modeling strategy includes those based on Monte Carlo simulation, renewal theory, and multivariate time series models.

[1]Professor of Hydrology, Hydrology and Water Resources Office, The University of Arizona, Tucson, Arizona.

HYDRAULIC GEOMETRY AND TIME-OF-TRAVEL FOR ILLINOIS STREAMS

John B. Stall[1]

A consistent pattern has been evaluated in which the width, depth, and velocity of flow in a stream change along the course of the stream with a constant frequency of discharge. These channel characteristics are termed *hydraulic geometry* and constitute an interdependent system which is described by a series of graphs having simple form, or by equations.

The data from 166 stream gaging stations in Illinois have been assembled and used to develop the parameters to define the hydraulic geometry of these streams. Results are presented as separate sets of equations for 18 river basins in Illinois. Stream characteristics are related to frequency of discharge and to drainage areas as independent variables.

Stream velocities computed from hydraulic geometry equations are used to compute time-of-travel in some Illinois streams. These check reasonably with velocities determined by using dye tracers.

[1]Engineer, Illinois State Water Survey, Urbana, Illinois.

HYDRAULICS OF LARGE BED ELEMENT CHANNELS

Harl E. Judd[1] and Dean F. Peterson[2]

This paper discusses theoretical means of characterizing size, size distribution, spacing, and shape of bed elements in hydraulically significant terms for large bed element streams; these are related to flume experiments using simulated stream beds. Large bed element channels are defined as those channels in which the bed elements extend through a major portion of the flow depth.

Observed bed and flow characteristics are reported for a number of natural stream sites located in Utah, Colorado, and New Mexico. Detailed measurements made at the different sites are analyzed to determine the effect of channel roughness, depth, and slope of flow characteristics of natural streams.

In nature, large bed element streams usually become paved with large boulders and such channels may approach a fixed bed condition insofar as the large bed elements are concerned, and only at very infrequent extreme discharge will the

dominant element be moved. Primarily this paper is concerned with the hydraulics of these streams at less than channel forming discharge.

Possibilities for use of large bed elements in open channel design are suggested.

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[1]Assistant Dean, School of Science, College of Southern Utah, Cedar City, Utah.

[2]Dean, College of Engineering, Utah State University, Logan, Utah.

OBSERVATIONS ON THE GEOMORPHOLOGY OF THE CENTRAL WASHITA RIVER BASIN

D. W. Goss,[1] A. R. Ross,[2]
P. B. Allen,[3] and J. W. Naney[4]

Data obtained from observation wells drilled to bedrock on 1-mile centers and several cross sections on 400-foot intervals have allowed a reconstruction of the valley shape prior to the onset of aggradation. The ancient valley was deep with sharp features and a broad bedrock terrace. Radiocarbon dates indicate the valley fill began prior to 11,200 years ago. The present valley has three terraces. Quartzite can be found throughout these terraces, but is more common in the highest terrace and at the alluvium-bedrock contact. This fact along with the large amount of valley alluvium and its age indicates that much of the alluvium may have been derived from the ancient Rocky Mountains via the Ogallala formation. It seems possible that the Ogallala formations once extended much further east than its present eastern boundary.

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[1]Geologist, U.S. Department of Agriculture, Chickasha, Oklahoma.

[2]Geologist, Oklahoma State University, Stillwater, Oklahoma.

[3]Research Hydraulic Engineer, U.S. Department of Agriculture, Chickasha, Oklahoma.

[4]Hydraulic Engineering Technician, U.S. Department of Agriculture, Chickasha, Oklahoma.

GEOMORPHOLOGY OF TYPICAL FLOOD-PLAINS

Frank F. Reckendorf [1]

Rivers may develop sequences of stepped levels which include both terraces and flood-plains. Chronological sequences of natural flood-plains are shown, which were partly separated and mapped based on: (1) the presence of scarps separating two or more flood plains; and (2) typical flood-plain geomorphic features. Typical flood-plain geomorphic features are discussed with photo examples and include: (1) oxbows; (2) oxbow lakes; (3) point bars; (4) meander scrolls; (5) sloughs; (6) natural levees; (7) sand splays; (8) old channels; and (9) modern channels and bars. In general, the younger the flood-plain, the more abundant or apparent are the geomorphic features. For natural perennial and ephemeral flood-plains, typical flood-plain morphologic features are more apparent the larger the watershed. Representative examples of multiple flood-plains and their morphology are given for the State of Oregon.

[1] Geologist, USDA, Soil Conservation Service, Salem, Oregon.

GENERAL LECTURE ANALYSIS OF TIME-SERIES DATA

G. H. Toebes [1]

An introduction to time-series analysis will be presented that is reasonably self-contained and directed towards the non-initiated. The nature of data and their elementary statistics will be reviewed, time-series analysis will be explained, and available techniques for obtaining correlation functions and spectra will be enumerated. Their interpretation and uses will be illustrated by a diverse collection of examples, drawn from such disciplines as hydraulics, hydrology, geomorphology, mechanisms, economics, and pollution control.

[1]Professor of Hydraulic Engineering, School of Civil Engineering, Purdue University, Lafayette, Indiana.

SOME TURBULENCE CHARACTERISTICS OF FIVE MAJOR RIVERS IN THE UNITED STATES

R. S. McQuivey [1]

A preliminary investigation of the longitudinal relative turbulence intensities, autocorrelations, power spectra, and scales of turbulence was made employing hot-film anemometry and a digital computing system. The vertical distributions of the above characteristics were measured in the Rio Grande, Columbia, Missouri, Mississippi, and Colorado Rivers over a wide range of hydraulic conditions. These data were also correlated with additional data including roughness parameters, bed forms, suspended sediment concentrations, sediment size, and the size of the systems.

The relative turbulence intensities increased in proportion to the increase in roughness. The suspended sediment concentrations and size of sediment in suspension were influenced not only by the relative turbulence intensities, but also by the bed forms. The autocorrelation provided information on the scales of turbulence for each system. The scales of turbulence are influenced not only by the size of the system, but by the roughness size and spacing.

The energy spectra provided information on how the energy is distributed with respect to frequency. As the size of the system is increased more energy is distributed in the low frequency range, i.e., less than 1 Hz.

[1]Research Hydraulic Engineer, U.S. Geological Survey, Fort Collins, Colorado.

SPECTRAL ANALYSIS—A PROTOTYPE STUDY

H. T. Falvey [1] and D. L. King [2]

A detailed knowledge of pressure fluctuations in high energy flows is often desirable for the design of hydraulic energy dissipators. For instance, some stilling basin energy dissipators utilize a dividing or trainer wall on the longitudinal centerline of the basin. If the frequency of pressure fluctuations within the flow happens to

correspond with the natural frequency of the wall, excessive wall vibrations may result.

The paper describes the spectral analysis techniques utilized by the Bureau of Reclamation to analyze fluctuating signals. The considerations which led to an analog analysis, accuracy of the analysis, and application of the results are illustrated in the analysis of pressure fluctuations obtained from a prototype stilling basin.

[1]Engineer, Research Division, U.S. Bureau of Reclamation, Denver, Colorado.

[2]Engineer, Research Division, U.S. Bureau of Reclamation, Denver, Colorado.

SESSION 3C-1

FLOODS IN NORTHERN CALIFORNIA—PAST AND PRESENT

Edward J. Helley [1]

Twice in the past 16 years, record-breaking floods have occurred over large areas of Northern California. On many streams, the peak discharges in both 1955 and 1964 were greater than any that had occurred during the period of record; and on some streams the 1964 peak exceeded any that had previously occurred during reasonably dependable local observation—in some instances, more than 100 years. Unprecedented changes in channel morphology and associated destruction of long-lived trees provides a basis for extending flood flow frequencies and enhances the understanding of channel processes.

Geomorphic and botanical evidence of a regional pre-historic flood are being investigated on major streams throughout Northern California. Blue Creek, a tributary to the Klamath River, is chosen as an example. Here ancient Redwood trees buried by this pre-historic flood were exhumed by the flood of December 1964. Radiocarbon analyses supplemented by ring counts established the date of flood burial at about A.D. 1560. This flood was approximately the same order of magnitude as the devastating flood of December 1964. Thus, the modern flood had occurred at least once in the last 400 years. The distribution of the ancient buried Redwoods with respect to low flow depth and channel alignment can be used to reconstruct ancient valley widths and channel slope.

[1]Hydrologist, U.S. Geological Survey, Menlo Park, California.

RIPPLE CONCENTRATION AND FRICTION FACTOR

Fred F. M. Chang [1]

Because roughness effects are expressed in terms of the size, shape and spacing of roughness elements, mean height and overall concentration of ripples are important parameters for describing the friction factor for the flow over ripple beds.

The total friction factor is the summation of grain-roughness friction factor and form-roughness friction factor. Nikuradse's formula for grain-roughness friction factor is adapted for the analysis of the grain-roughness friction factor. However, it is assumed that the skin friction is not effective in the wake zone behind the ripples, thus Nikuradse's formula is modified by the ratio of the effective area to the total area.

For the form-roughness friction factor, the energy loss due to sudden expansion of the flow behind the ripples is considered. Like the flow in a pipe with a sudden expansion, the expansion loss is found to be a function of expansion ratio and mean velocity of the flow.

Total friction factor for the flow over a ripple bed can be expressed as

$$f = [1 - \frac{6e}{\cot\phi}] f'_g + 4f_e \frac{e}{\cot\phi} \frac{y_n}{H}$$

where

f'_g = Nikuradse's formula for grain-roughness friction factor,

e = exposure parameter (parameter related to overall concentration of ripples ,)

ϕ = angle of repose of sediment,

f_e = coefficient of expansion loss behind the ripple,

y_n = normal depth of flow, and

H = mean height of ripples

In the above equation, the coefficient of expansion loss, f_e, is found to be only a function of the relative height of the ripples.

[1]Associate Professor, Civil Engineering Department, South Dakota State University, Brookings, South Dakota.

SESSION 3C-3

STABILIZATION OF CHANNELS IN COARSE, NON-UNIFORM BED MATERIAL

John Hamilton [1] and D. B. Simons [2]

Transmountain diversion of water into a stable river traumatically disrupts a dynamic equilibrium which the river has achieved during its recent geologic history. The river is forced to adjust itself to a new stability commensurate with its new flow conditions. One adverse effect is severe degradation of the channel bed which, in turn, results in the excessive transport of sediment to the downstream reservoir. Hence the engineer is faced with the difficulty of numerically describing the behavior of coarse, non-uniform bed material. The ability of this material to terminate degradation through a process of bed armoring is poorly defined since the numerous flume experiments deal primarily with fine, uniform sand. A procedure for stabilization of rivers with coarse bed material by construction of small dams is presented and the concept is developed numerically. The study is concluded by a field investigation of a project which employs a concept similar to the one developed herein. Changes in the stream bed, recorded over more than two years of investigation, illustrate the validity and practability of the procedure.

[1] Hydraulic Engineer, Black and Veatch Consulting Engineers, Denver, Colorado.

[2] Associate Dean for Engineering Research, Colorado State University, Fort Collins, Colorado.

SESSION 3C-4

CHANNEL RETROGRESSION DOWNSTREAM OF DIVERSION STRUCTURES

Khalid Mahmood [1]

Rating curves in alluvial channels exhibit variations, some of which may be related to individual floods (discontinuities) and others that may be seasonal or long term in nature. These variations are caused by changes in discharge, sediment inflow, energy gradient, temperature, etc., and are brought about through changes in bed form, bed elevation, channel length, alignment, etc. Downstream of the diversion structure, an alternating retrogression and accretion cycle is created which is superimposed on the variations inherent in the site.

The safe discharge capacity of a diversion weir is determined by two conditions. For aggraded conditions of the stream, the design elevation of the levees upstream of the

weir determines the maximum safe discharge that can be passed. For retrogressed conditions of the stream, on the other hand, the hydraulic jump limit curve defines this capacity. The aggraded condition is not critical because the discharge capacity can be increased by a small encroachment on the free board and also because the levees can be raised with comparative ease and small costs. The retrogressed condition is, however, more critical because of smaller tolerance in sequent depths available in hydraulic jump type stilling basins, and the difficulties involved in major remodeling of the basins.

For the design of a diversion weir, maximum and minimum gage discharge envelopes are, therefore, to be determined. The minimum envelope is more critical not only because of the reasons stated above, but also because the stilling basin level effects the cost of the structure due to dewatering.

In the low, wide, and shallow diversion structures of the plains of West Pakistan, the weirs provide an afflux on the order of 20 feet at low stages and 3 feet at design flood stage. Also, the river discharges vary about 50 times from the low winter to high summer stages. Rating curve variations inherent in these sites are thus of the same order as those subsequently induced by the structures. This aspect distinguishes these structures from higher structures.

In connection with a serious retrogression problem now being experienced at Taunsa Barrage on the Indus River in West Pakistan, the writer made an analysis of the effect of diversion structures on the stage discharge relation. The following conclusions have been arrived at:

i. For the alluvial sites in West Pakistan, the maximum and minimum stage-discharge envelopes can be approximated by straight lines on log-discharge versus stage plottings of data for any considerable length of time.

ii. For a given discharge, the difference between the maximum and minimum stage envelopes gives a good estimate of the anticipated retrogression. This difference may be subtracted from the minimum stage envelope to provide the design retrogressed stage discharge curve.

iii. Contrary to popular belief, the minimum stage may not be experienced in the first few cycles of retrogression. The minimum stage is strongly dependent on antecedent floods and a super flood may cause the lowest ever stage in the following seasons.

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[1]Executive Engineer, Irrigation Research Institute, Lahore, West Pakistan.

A DYNAMOMETER FOR MEASURING FORCE COMPONENTS ON LARGE ROUGHNESS ELEMENTS IN OPEN CHANNEL FLOW

Calvin G. Clyde [1] and Edmund D. H. Cheng [2]

In a study of incipient motion of large roughness elements in turbulent open channel flow, it was desirable to measure continuously the x, y, and z components of force on an individual roughness element. The semiconductor strain gage dynamometer described in this paper was developed to fill this need.

The device is attached to the flume bed to support the roughness element (a one foot diameter sphere) and measures the components of total force on the sphere. The measured force components are recorded, along with other flow parameters such as the fluctuating velocity near the sphere, as a function of time by a light beam oscillograph. The construction, response, sensitivity, and other characteristics of the device are described.

[1]Assistant Director, Utah Water Research Laboratory, Utah State University, Logan, Utah.

[2]Graduate Research Assistant, Utah Water Research Laboratory, Utah State University, Logan, Utah.

A FLOW-SENSING, COMPUTING AND PLOTTING SYSTEM

Gary V. Weise, [1] John R. Chappell, [2] and John R. Verna [3]

The need for a rapid, accurate, and durable instrument to measure liquid velocities can be satisfied by combining new electronic components with an already much-proven pitot cylinder. Neither hot wire nor hot film systems can meet the above demands, even though their frequency responses are better. The system reported here measures, calculates, and plots pressure and velocity surveys while maintaining the probe in alignment with the direction of the flow.

Flow conditions at the pitot cylinder are measured by diaphragm-type, electronic pressure transducers. Signals from one differential transducer drive a servo system which orients the probe into the direction of flow within $\pm$ one-fourth of a

degree. The other transducer signals drive a solid-state analogue computer where axial velocity and pressure ratios are calculated. The computer is constructed using modular circuit cards and can be modified somewhat to obtain different types of reduced data. These data are then recorded on X-Y plotters as the probe traverses the flow passage.

The time required to produce readily meaningful data using this system is less than one percent of the time previously required. Since the system can be nondimensionalizing, its response is good in unsteady flows. While system accuracy is limited by the accuracy of the transducers, it has been possible to obtain velocity measurements to ± one-half percent. The system can be applied where velocity or pressure profiles are to be measured in fluid compatible with the transducers. It has been used in turbulent water flow at velocities from 15 to 40 feet per second.

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[1]Laboratory Analyst, Newport News Shipbuilding and Dry Dock Company, Hydraulics Laboratory, Newport News, Virginia.

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[3]Staff Civil Engineer, E. D'Appolonia Consulting Engineers, Inc., Pittsburgh, Pennsylvania.

SESSION 3D-3

CORRELATING SUBSURFACE PRESSURE FLUCTUATIONS WITH SURFACE WAVES

Paul C. Liu[1]

The Great Lakes Research Center has operated five pressure-cell wave gages in the Great Lakes. The pressure wave records were "processed" to convert subsurface pressure fluctuations to corresponding surface waves. A typical approach to this problem is application of the classical pressure response function. However, the irregular and stochastic essence of nature waves limits the applicability of classical wave theory, and efforts to develop empirical correlations using spectral analysis appear practicable. Two such empirical studies have been undertaken, which involved analyzing simultaneous recordings of surface and pressure waves recorded at the Lake Michigan Research Tower near Muskegon, Michigan, during the summer and fall seasons of 1965, 1967, and 1968:

(1) Surface and pressure waves were treated as input and output, respectively, of a system analogous to that in stationary random signal theory, and transfer functions were obtained by spectral analyses. Correlation of the transfer function with the classical pressure response function then led to an empirical expression that

was used to estimate the wave attention produced by the water layer over the pressure cell.

(2) Based on the similarity nature of normalized deep-water wave spectrums, an empirical spectral equation has been developed. This spectral equation, considered as "universal" for surface waves, is characterized by the two parameters of variance of the wave profiles and frequency of peak energy in the spectrum. In addition, relationships between measured surface and pressure waves for the two parameters were developed. From these relationships and the spectral equation, surface wave spectrums are obtained from calculated pressure wave spectrums.

Both of these approaches have been tested and yield good agreement. The second approach, which is presented for the first time, is especially simple efficient.

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SESSION 3D-4

ACQUISITION AND ANALYSIS OF TURBULENT WATER VELOCITIES

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Turbulent velocity measurements have been made for the flow of water in a 5 in. circular pipe for a wide range of Reynolds numbers. Simultaneous measurements of the axial and radial velocity components were obtained at several radial positions. The fluid velocities were converted directly into electrical signals through the use of magnetohydrodynamics techniques. Voltage signals from the 3-electrode MHD probe were conditioned and amplified using a specially designed dual-channel amplifier. The amplified signals were then recorded in analog form by a precision FM magnetic tape recorder.

Reduction of the recorded data were performed on a hybrid computer. Autocorrelations and cross-correlations were computed from digital samples of the two signals. Correlations were computed for lag intervals of from 0.0001 sec to 1 sec. The autocorrelations were transformed digitally to give power spectral density functions for the two signals. Spectral densities were computed for frequencies from 0.5 Hz to 5000 Hz. The analog part of the hybrid computer was used to filter the signals prior to sampling and to measure the variances and convariances of the two signals.

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