TECHNICAL REPORT H-69-10

MECHANICS OF FLOW FROM STRATIFIED RESERVOIRS IN THE INTEREST OF WATER QUALITY

Hydraulic Laboratory Investigation

by

J. P. Bohan

J. L. Grace, Jr.

July 1969

Sponsored by

U. S. Army Engineer Districts
Savannah and Philadelphia

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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FOREWORD

The experimental investigation reported herein was approved by the Director of the U. S. Army Engineer Waterways Experiment Station on 20 July 1966 as an In-House Laboratory Initiated Research Project. In order to expedite the program, additional financial support was authorized by the Office, Chief of Engineers, on 23 September 1966 at the joint request of the U. S. Army Engineer Districts, Philadelphia and Savannah. The studies were conducted in the Hydraulics Division of the Waterways Experiment Station during the period September 1966 to March 1969 under the direction of Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division, and Mr. T. E. Murphy, Chief of the Structures Branch. The tests were conducted by Mr. J. P. Bohan under the supervision of Mr. J. L. Grace, Jr., Chief of the Spillways and Conduits Section. This report was prepared by Messrs. Bohan and Grace.

Messrs. O. F. Reyholic of the North Atlantic Division, L. G. Leach of the South Atlantic Division, G. R. Drummond of the Philadelphia District, and J. W. Harris of the Savannah District visited the Waterways Experiment Station during the investigation phase of the study to discuss testing and correlate design work with experimental results. Mr. S. B. Powell of the Office, Chief of Engineers, observed experiments and reviewed results during conduct of the investigation.

COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE, were Directors of the Waterways Experiment Station during the conduct of the investigation and preparation and publication of this report. Messrs. J. B. Tiffany and F. R. Brown were Technical Directors.

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NOTATION

A Cross-sectional area of the zone of withdrawal, sq ft

A_o Area of the orifice opening, sq ft

b Width of the reservoir section, ft

D Height of a square orifice, ft

g Acceleration due to gravity, ft/sec^2

H Distance from the lower limit to the upper limit of the zone of withdrawal, ft

ΔH Head differential on the orifice, ft

K $\displaystyle\int_0^{Y_1} \left(1 - \frac{y_1\,\Delta\rho_1}{Y_1\,\Delta\rho_{1m}}\right)^2 dy_1 + \int_0^{Y_2} \left(1 - \frac{y_2\,\Delta\rho_2}{Y_2\,\Delta\rho_{2m}}\right)^2 dy_2$

Q Discharge, cfs

t Time, sec

v_1 Local velocity in the zone of withdrawal at a distance y_1 below the elevation of maximum velocity V, fps

v_2 Local velocity in the zone of withdrawal at a distance y_2 above the elevation of maximum velocity V, fps

V Maximum velocity in the zone of withdrawal, fps

$\overline{V}$ Average velocity in the zone of withdrawal, fps

V_o Average velocity through the orifice, fps

V_w Velocity of flow over the weir, fps

y_1 Vertical distance from the maximum velocity V to the corresponding local velocity v_1, ft

y_2 Vertical distance from the maximum velocity V to the corresponding local velocity v_2, ft

Y_1 Vertical distance from the maximum velocity V to the lower limit of the zone of withdrawal, ft

Y_2 Vertical distance from the maximum velocity V to the upper limit of the zone of withdrawal, ft

Z_o Vertical distance from weir crest to the interface, ft

Z_1 Vertical distance from the orifice ℄ to the lower limit of the zone of withdrawal, ft

Z_2 Vertical distance from the orifice ℄ to the upper limit of the zone of withdrawal, ft

ρ_o Fluid density at the elevation of the orifice ℄, g/cc

$\Delta\rho_1$ Density difference of fluid between the elevations of the maximum velocity V and the corresponding local velocity v_1 , g/cc

$\Delta\rho_2$ Density difference of fluid between the elevations of the maximum velocity V and the corresponding local velocity v_2 , g/cc

$\Delta\rho_{1m}$ Density difference of fluid between the elevations of the maximum velocity V and the lower limit of the zone of withdrawal, g/cc

$\Delta\rho_{2m}$ Density difference of fluid between the elevations of the maximum velocity V and the upper limit of the zone of withdrawal, g/cc

$\Delta\rho_1'$ Density difference of fluid between the elevations of the orifice ℄ and the lower limit of the zone of withdrawal, g/cc

$\Delta\rho_2'$ Density difference of fluid between the elevations of the orifice ℄ and the upper limit of the zone of withdrawal, g/cc

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
square feet	0.092903	square meters
feet per second	0.3048	meters per second
cubic feet per second	0.0283168	cubic meters per second
feet per second per second	0.3048	meters per second per second
Fahrenheit degrees	5/9	Celsius or Kelvin degrees*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

SUMMARY

Investigations were conducted to determine the characteristics of the withdrawal zone resulting from the release of flow through an orifice from a randomly stratified reservoir in experimental facilities for the purpose of developing means of predicting the quality of water discharged through similar openings in prototype intake structures. Distributions of density, generated by differentials in both temperature and dissolved salt concentration, and velocity were observed at various locations within a 1-ft-wide channel upstream of 0.08- and 0.16-ft-square orifices. These data were used to develop generalized expressions describing the limits of the zone of withdrawal and the distribution of velocities therein.

In certain cases, the proximity of the free surface and/or bottom boundary may dictate the upper and/or lower limits of the zone of withdrawal. Means were developed (Appendix A) for evaluating the conditions under which these boundaries dictate the limits of the withdrawal zone and for determining the distribution of velocities within a zone of withdrawal restricted by boundary conditions.

A sample problem (Appendix B) is presented to illustrate application of the results to determine the maximum discharge that may be released through a square orifice for a given set of conditions without exceeding the limits of a desired hypothetical zone of withdrawal. The example also illustrates how the actual limits of the zone of withdrawal and the velocity distribution therein are determined. A method is illustrated for predicting the dissolved oxygen content and/or other water quality parameters of the outflow provided the vertical distributions of these parameters in the reservoir are known.

A FORTRAN IV program is presented in Appendix C. This program can be used to solve three different approaches to the selective withdrawal problem: (1) determination of the allowable discharge for selected withdrawal limits and orifice size and elevation; (2) determination of the withdrawal zone characteristics for a selected discharge and orifice size and elevation; and (3) determination of the allowable discharge and orifice elevation for selected withdrawal limits and orifice size. The density and/or temperature profile in the reservoir must be known or assumed for all three conditions.

The effect of orifice shape on the withdrawal characteristics was tested and analyzed after the draft of this report was prepared. The results were believed to be pertinent and are discussed briefly in the Discussion section of this report.

MECHANICS OF FLOW FROM STRATIFIED RESERVOIRS IN THE INTEREST OF WATER QUALITY

Hydraulic Laboratory Investigation

PART I: INTRODUCTION

General Characteristics of Reservoirs

1. Although water quality is not definitive since each user has his own standards and any one user may have an entirely different attitude toward the quality of water which he receives for use and that which he wastes, the public has become increasingly aware of the term "water quality" as it applies to personal consumption and recreational use. Public Law 660 as amended by the Federal Water Pollution Control Act Amendments of 1961 - (PL 87-88), the Water Quality Act of 1965 - (PL 89-234), and the Clean Water Restoration Act of 1966 were significant steps toward an accelerated national attack on pollution and enhancement of the quality and value of our water resources.

2. In a broad sense, reservoir operation in the interest of water quality has been common practice throughout history, but operation in the past has been governed primarily by other single or multiple purposes for which the projects were constructed. The need for increased efforts to obtain optimum use of our water resources becomes more evident with the growth of population and industry and the increased demands on our water resources.

3. Solar energy and the process of photosynthesis generally assist in supporting the oxygen content of impounded water. Circulation induced by wind, convection, and the flow of water entering and being withdrawn from the impoundment assists in distributing such water to all parts of the reservoir. However, circulation may be restricted by the presence of a thermocline (a layer of sharp temperature difference) and the corresponding stratification of the reservoir. Stratification due to chemicals or dissolved solids and turbidity or suspended solids is possible also in

freshwater reservoirs. Water below the thermocline or interface is generally void of sunlight due to the depth and/or turbidity involved, and its oxygen content is diminished by the decay of settling matter. Products of oxygen reduction will accumulate, and the water may eventually acquire an unpleasant taste and odor or become unfit for supply. Thus, the thermal stratification becomes a chemical stratification also. No attempt is made herein to discuss the use and/or effectiveness of pneumatic and hydraulic methods of preventing stratification by inducing circulation or the resulting effect of such methods on the quality of impounded waters. The need for increased knowledge regarding water quality characteristics of reservoirs, the mechanics of stratified flow in reservoirs, and the mechanics of selective withdrawal to permit prediction of the changes in water quality of proposed reservoirs during the planning stage is apparent. This information is also required for the proper design of structures for selective withdrawal, and the determination of the method of operation required for effective control of both the thermal and the chemical quality of releases from stratified reservoirs. This is particularly true in the case of reservoirs and multipurpose projects presently in the planning and design stages in various offices of the U. S. Army Corps of Engineers for which specific requirements relative to the thermal and chemical quality of releases are desired.

4. Investigations of reservoir water quality are being conducted by various private and governmental agencies throughout the United States. In time, continued investigations of the physical, chemical, and biological characteristics of existing streams and reservoirs will provide data regarding the mechanics of stratified flow in reservoirs and knowledge sufficient for the development of accurate ways and means of predicting the seasonal variation in the quality of future impoundments and the realization of the idealistic optimum use of our water resources. Such data upstream and downstream of existing regulating structures will be useful in evaluating the effectiveness of various structures and means of regulation on reaeration and general improvement of our water resources. In reality, there are many unknowns relative to the physical, chemical, and biological characteristics of existing streams and reservoirs and the effects of

various multipurpose requirements on the quality of impounded water. These can be determined only by continued study of the general characteristics of existing streams and reservoirs.

The Problem

5. Planners and designers are faced with the problem of predicting the quality of impounded water and developing means for effectively controlling the thermal and chemical quality of releases from stratified reservoirs passed through powerhouses, spillways, and outlet works. Information for predicting general water quality characteristics and the effectiveness of structures in selectively withdrawing releases from various levels of a reservoir is urgently needed at present for the design of multipurpose projects in which specific thermal and chemical requirements for the releases are desired based on existing and/or future needs. To ensure that these requirements can be met most of the time, multilevel intake structures and submerged weirs for selective withdrawal purposes are proposed for several multipurpose projects being designed in various offices of the Corps of Engineers. On certain projects, selective withdrawal is desired not only during periods of low flow releases in late summer and early fall when the reservoirs may be highly stratified, but also during reservoir flushing operations when release of bottom water is desired. Certain projects require relatively high rates of outflow during normal operation, and the blending of water from intermediate levels with surface water may be necessary for successful operation. The desire to release good quality water regardless of conditions, including discharge, will require a procedure for monitoring the characteristics of water within the reservoir as well as that withdrawn. Therefore, knowledge of the pattern of flow to be expected in the immediate and upstream vicinity of various intake structures, and of the effect on withdrawal of the size, shape, and vertical spacing of multilevel openings, is desired to permit prediction of the level of the reservoir from which releases can be anticipated and the optimum location for fixed monitoring stations within the reservoir. Evaluation of the effectiveness of submerged skimming weirs or thermal barriers

in preventing the intrusion of cold water void of dissolved oxygen into powerhouse intakes and single-level outlet works is of primary concern also.

Background, Purpose, and Scope of Study

6. Obviously, the U. S. Army Engineer Waterways Experiment Station (WES) is interested in developing model techniques for solution of these and other problems associated with the mechanics of stratified flow and selective withdrawal. During 1966, the Director of WES approved an In-House Laboratory Initiated Research Project to assist in accomplishing this task. In addition, the Office, Chief of Engineers, and, in turn, the Philadelphia, Savannah, and St. Louis Districts approved model studies concerned with the mechanics of selective withdrawal from stratified reservoirs for the purpose of assisting in the design and evaluation of certain proposed structures, specifically the outlet works for Beltzville, New Hope, and Meramec Park Reservoirs. The Savannah and Philadelphia Districts also authorized funds to supplement the generalized tests of the In-House Research Project, the basis of this report.

7. A continuing review of literature was initiated during September 1966. Generation of stratification or density differentials by the addition of dissolved and/or suspended solids and by means of temperature differentials was considered, and the present consensus of engineers at WES is that the use of dissolved solids (salt) is the most practical method of generating density differentials in WES facilities which are subject to the temperature variations of the local climate. Investigations concerned with the development of model techniques, instrumentation, and tests of a generalized nature were undertaken to determine the characteristics of the withdrawal zone upstream of an orifice for various conditions of stratification in order to develop generalized equations for use in predicting the quality of water discharged through similar openings in prototype intake structures.

8. It was considered that any practical method for predicting the quality of water discharged through an inlet should be based upon the extent of the zone of withdrawal and the distribution of velocities within this zone. Then, if the distribution of one or more water quality parameters

is known, the resulting value of temperature, dissolved oxygen, or other parameter of the release could be computed. The facilities, experiments, test results, and data analyses utilized for determining generalized equations that describe the extent of the zone of withdrawal and the distribution of velocities therein are the basis of this report and are described in subsequent sections.

PART II: EXPERIMENTAL FACILITIES

Description

9. The experimental facilities (fig. 1) contained a square orifice with rounded entrance cut in a piece of plastic and located in the center of a 1-ft*-wide channel. This orifice simulated a typical opening, such as that proposed for the New Hope Reservoir intake structure, to scales of 1:50 and 1:100. Approximately 18 ft of the 1-ft-wide, 2-ft-deep channel was provided upstream of the orifice. A headbay 40 ft long, 16 ft wide, and 4 ft deep was provided upstream of the channel for the purpose of providing a relatively large reservoir supply of salt water. Water was supplied by a pipe and weir box that extended across the full width of the headbay. The weir box was supported by screw jacks in order that the base or lip of the box could be set at the interface or surface of the saline water. Fresh water was slowly introduced through the box and over the broad-crested weir and saline water in order to establish the upper

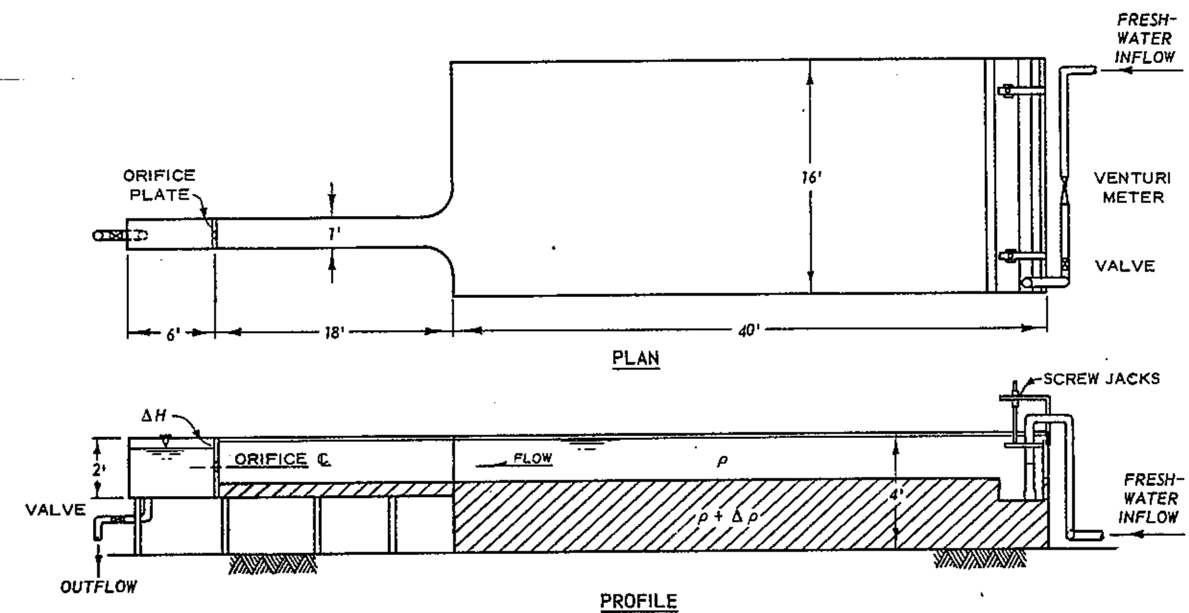

Fig. 1. Experimental facilities

* A table of factors for converting British units of measurement to metric units is presented on page xi.

stratum. Approximately 6 ft of channel was provided downstream of the orifice with a drain pipe and valve for control of the head differential on the orifice. The orifice was calibrated and used for measuring the quantity of the outflow. A venturi meter was used to measure the quantity of fresh water supplied through the weir box at the upper end of the facilities.

10. The lower, denser stratum was generated by filling the headbay and channel to a predetermined level with fresh water and mixing in salt and dye to give the desired density and red color. The weir box was placed at the surface of the saline water and fresh water was placed over the saline water to create the upper stratum. Initially, a very distinct two-layer stratification existed; however, the variable temperature of the atmosphere generally heated and cooled the upper stratum during the day and night to the extent that it was necessary to observe temperatures as well as salinity in order to determine an accurate measure of the density gradient in the experimental facilities.

Instrumentation

11. Temperature and salinity gradients in the facilities were measured in place by means of commercially available instrumentation (see fig. 2). A conductivity probe, 5/16 in. in diameter with 1/16-in.-diam platinum electrodes, was used to measure conductivity. The platinum electrodes were approximately 1/8 in. long and spaced 1/16 in. apart. The probe was interconnected in one leg of a Wheatstone bridge circuit within the conductivity indicator. A millivoltmeter was connected to the conductivity indicator and provided a digital readout of the conductivity. Since temperature compensation was not provided in the conductivity probe, it was calibrated in different concentrations of saline water at different temperatures. The actual density of the fresh and saline waters used in the facilities and for calibration purposes was determined by means of a gravimetric balance since the sump water was not distilled water. This calibration could be checked quite easily, since conductivity varies linearly with the salt concentration which in turn varies linearly with the density.

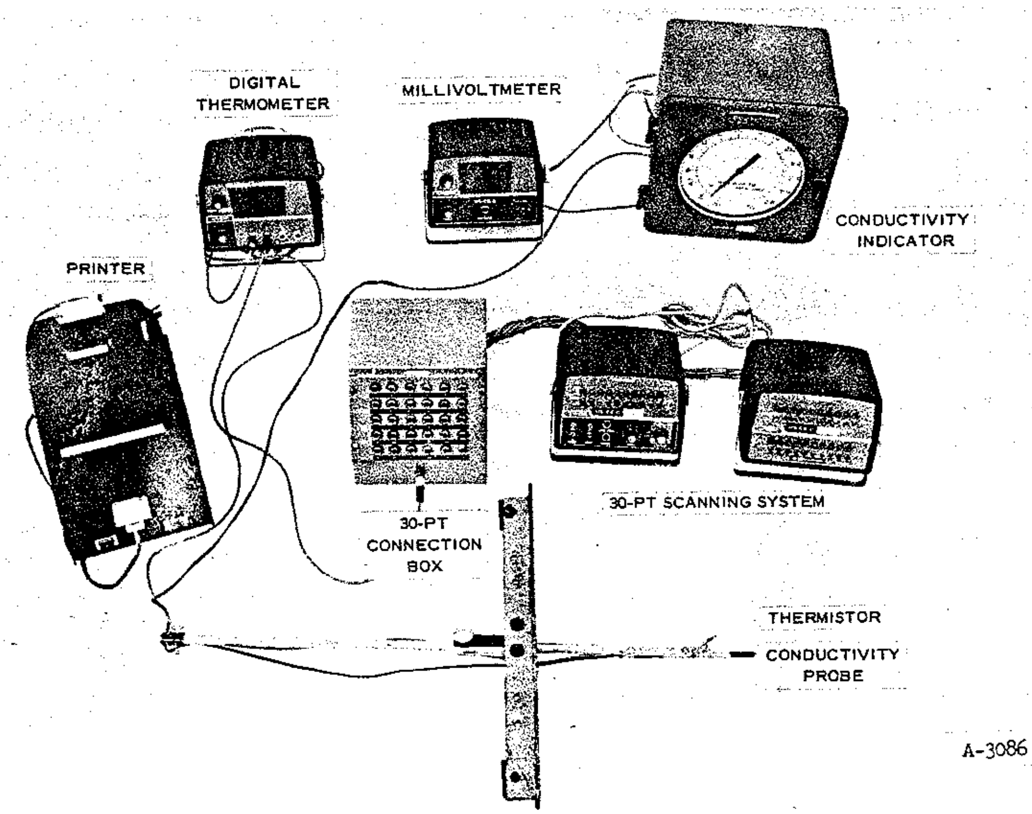

Fig. 2. Instrumentation used in experimental facilities

Thermistors were used to measure the water temperature in the model facility. Thirty thermistors were used throughout the system, and these were read by one channel of a digital thermometer through a 30-point connection box and a 30-point scanning system. The scanning system and digital thermometer were, in turn, connected to a two-channel printer so that the 30 temperatures could be read and printed in approximately 1-1/2 min. A single thermistor was connected to a point gage along with the conductivity probe, as shown in fig. 2, to obtain vertical profiles of conductivity and temperature for determination of the density of the fluid in the facilities.

PART III: TESTS AND RESULTS

Test Procedure

12. After a two-layer stratification had been generated, the test was initiated by introducing a given discharge of fresh water into the headbay and releasing an equal amount through the orifice, control valve, and drain. All of the tests were conducted with steady, uniform flow conditions. Approximately 1 hr was required for the secondary currents induced by initiating and/or changing the flow to settle out or become steady and uniform. Velocity distributions were obtained by dropping dye particles into the flume at three locations (1, 3, and 8 ft upstream of the orifice) and photographing the resulting streaks at each location with movie cameras. A typical dye streak is shown in fig. 3. The indicated upper and lower limits of the withdrawal zone occur at the points of zero velocity in

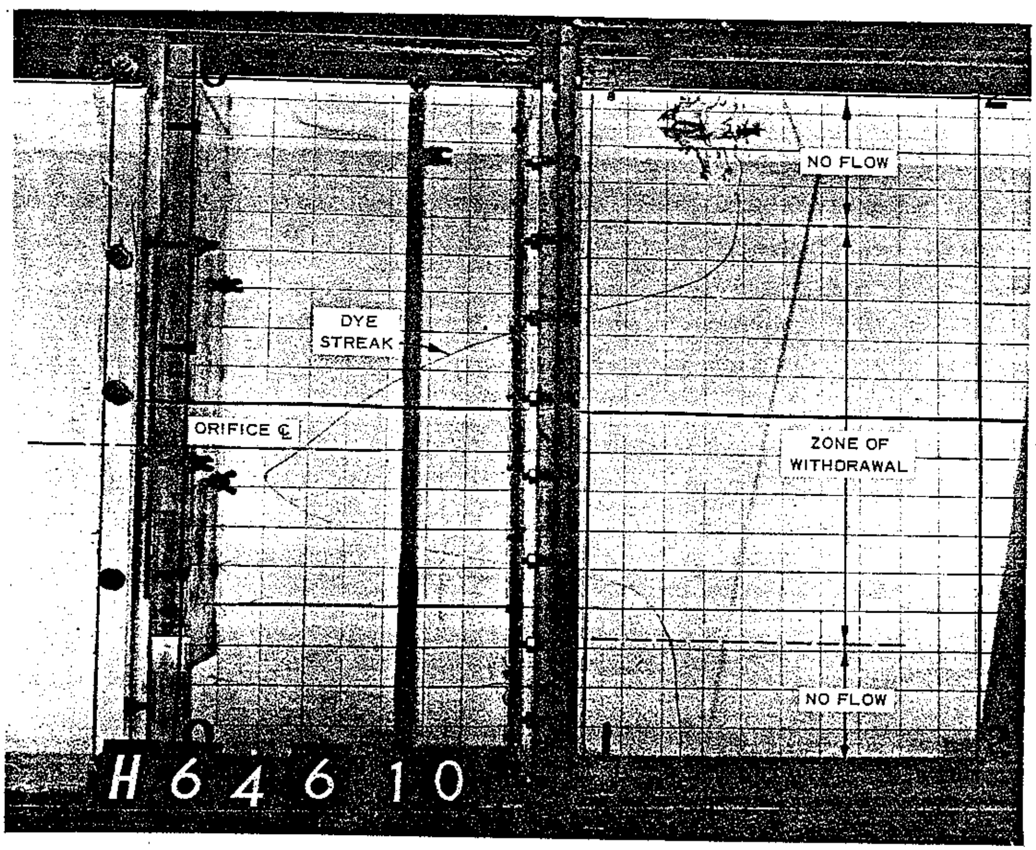

Fig. 3. Typical dye streak

the flow. Temperature and conductivity profiles were then obtained at the locations 1 and 8 ft upstream of the orifice. Temperatures of the water within the headbay and of both the inflow and outflow were observed also.

Basic Data

13. The movies of the dye streaks and grid system painted on the plastic side of the channel were projected, and the frame at which the streak reached the bottom of the channel was traced and used as the reference time $t = 0$. The film was projected again and stopped three other times so that the dye streaks could be traced. The error due to distortion and refraction was taken into account at this point. A typical set of traced dye streaks is shown in fig. 4. The time between the streaks was determined based upon the known speed of the camera and the number of frames between the traced streaks. The velocity at every 0.1 ft of depth was calculated by dividing the scaled horizontal distance between the traced streaks by the increment of time elapsed. Thus three velocity distributions were obtained at each location upstream of the orifice, and these were averaged to yield one representative distribution.

14. Temperature and conductivity readings were converted to determine densities at various depths, and these values were plotted to

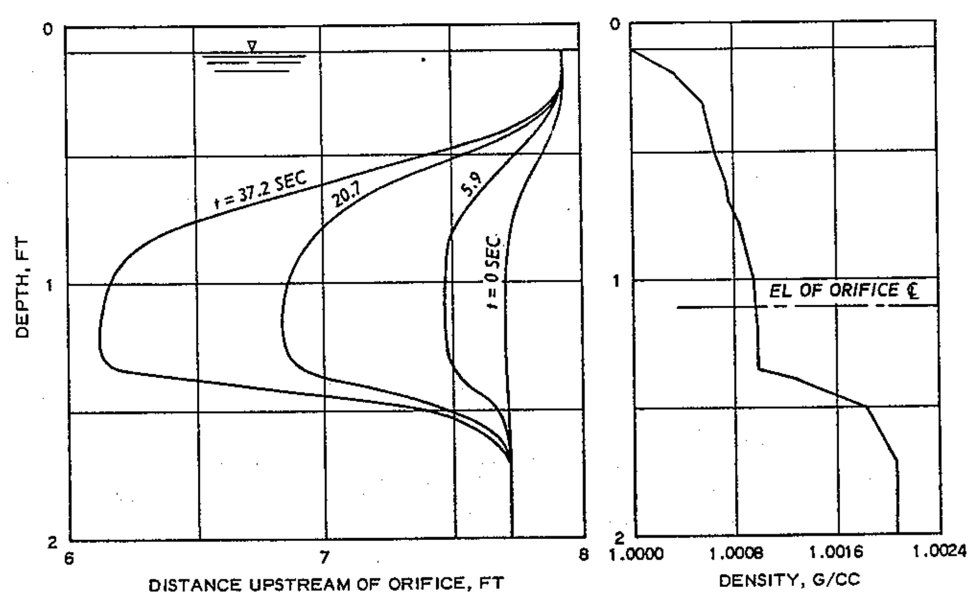

Fig. 4. Typical dye streaks and density profile

determine the density profile at the locations 1 and 8 ft upstream of the orifice. A comparison of the density and velocity distributions at the different locations upstream of the orifice showed very close agreement. It appeared that only those streaks within a distance of about three times the height of the orifice were distorted materially by the contractive effects of the orifice. However, since the thickness of the zone of withdrawal did tend to increase very slightly in an upstream direction, it was decided that only the density and velocity distributions obtained at the location 8 ft (50 times the orifice height) upstream of the orifice would be used in the data analyses. These distributions are presented in plates 1-3.

Data Analyses

15. General observations as well as those made with the dye streaks indicated the existence of a zone of withdrawal above and below which there was no flow (fig. 3). It was desirable and necessary to describe the upper and lower limits of this zone of withdrawal. The important variables appeared to be the size of the orifice, the velocity through the orifice, the density profile, and the vertical location of the orifice relative to the density profile. A definition sketch of the variables involved is shown in fig. 5. The data were plotted as shown in plate 4 in terms of the

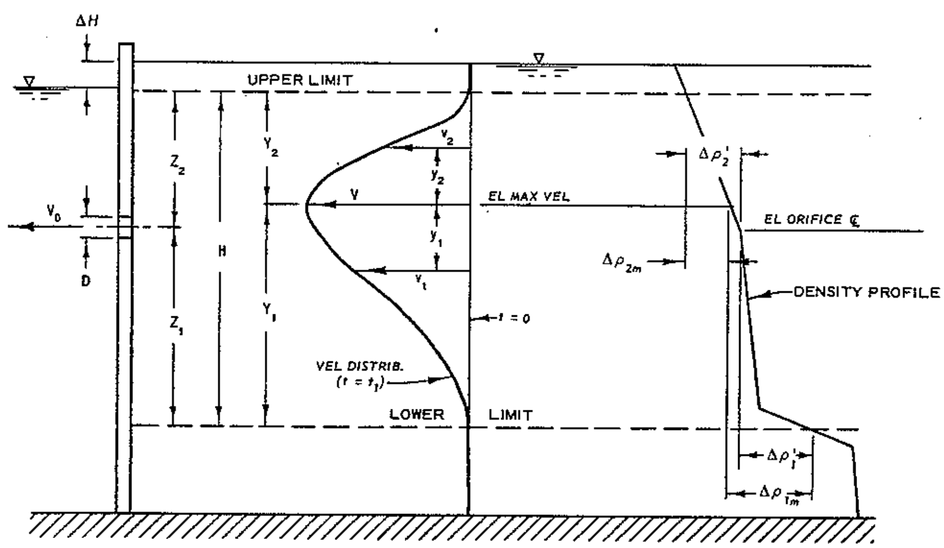

Fig. 5. Definition sketch of variables

densimetric Froude number and the ratio Z/D . The equation of the line shown is

$$V_o = \left(\frac{Z}{D}\right)^2 \sqrt{\frac{\Delta\rho'}{\rho_o} gZ} \tag{1}$$

where

V_o = average velocity through the orifice, fps

Z = vertical distance from the orifice ℄ to the upper or lower limit of the zone of withdrawal, ft

D = height of a square orifice, ft

$\Delta\rho'$ = density difference of fluid between the elevation of the orifice ℄ and the upper or lower limit of the zone of withdrawal, g/cc

ρ_o = density of fluid at the elevation of the orifice ℄, g/cc

g = acceleration due to gravity, ft/sec^2

The quantity $V_o \Big/ \sqrt{\frac{\Delta\rho'}{\rho_o} gZ}$ is defined as the densimetric Froude number, where $\frac{\Delta\rho'}{\rho_o} g$ represents the modified gravity force. As indicated in plate 4, two different sizes of orifices (0.08 and 0.16 ft square) were tested and good correlation can be seen between them. This relation is valid for both the upper and lower limits of the withdrawal zone, except in cases where the upper or lower limits of the zone intersect either the free surface or bottom boundary, respectively. A method for determining whether the withdrawal zone extends to the free surface or bottom boundary and a technique for determining the velocity distribution for such conditions are presented in Appendix A.

16. The movies of the dye streaks indicated that the maximum velocity within the zone of withdrawal, in most cases, did not occur at the elevation of the orifice center line (℄). The data shown in plate 4 indicate that the upper and lower extents of the zone of withdrawal are functions of the area and densimetric Froude number of flow through the orifice. Data analyses indicated that the maximum velocity occurred at the elevation of the orifice ℄ only when the withdrawal zone was vertically symmetrical about the elevation of the orifice ℄ . The maximum velocity occurred below the orifice ℄ when the vertical extent of the lower limit of the withdrawal zone was less than that of the upper limit. Similarly, the maximum velocity

occurred above the orifice ℄ when the distance from the orifice ℄ to the lower limit was greater than the distance from the orifice ℄ to the upper limit (fig. 6). A plot indicating the relative position of the maximum

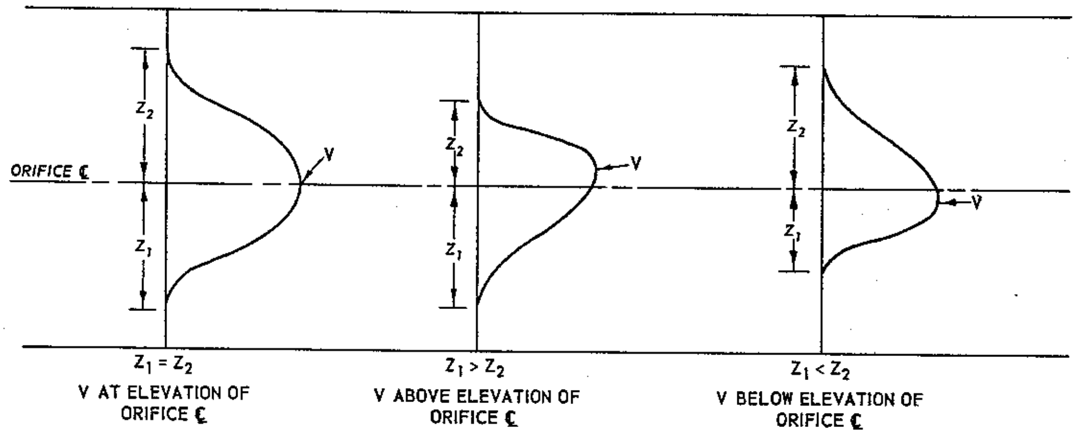

Fig. 6. Location of maximum velocity relative to elevation of orifice center line

velocity in terms of Y_1/H and Z_1/H is shown in plate 5. The variables are illustrated in fig. 5, and defined as follows:

Y_1 = the distance from the elevation of maximum velocity to the lower limit of the zone of withdrawal, ft

H = the thickness of the withdrawal zone $(Z_1 + Z_2)$, ft

Plate 5 can be used to determine where the maximum velocity will occur, after Z_1 and Z_2 have been determined from equation 1.

17. The next objective was that of developing a dimensionless velocity distribution so that for any given situation the velocity distribution could be described. The problem was approached by first plotting the ratios y_1/Y_1 and y_2/Y_2 against v_1/V and v_2/V, respectively, where:

y_1 = the vertical distance from the maximum velocity down to a point on the velocity distribution, ft

y_2 = the vertical distance from the maximum velocity up to a point on the velocity distribution, ft

Y_1 = the vertical distance from the maximum velocity to the lower limit of the zone of withdrawal, ft

Y_2 = the vertical distance from the maximum velocity to the upper limit of the zone of withdrawal, ft

v_1 = the local velocity at y_1 , fps

v_2 = the local velocity at y_2 , fps

V = the maximum velocity in the zone of withdrawal, fps

These plots, not shown herein, produced various unsymmetrical shapes and indicated the need for incorporating the effect of density. Observations of the velocity and density distributions indicated that a sudden reduction in velocity was always associated with an abrupt increase in density. Since density and pressure are directly related and pressure and velocity are indirectly related, it seems quite logical that the observed phenomenon should occur and thus distort the velocity distributions. The most satisfactory fit of the experimental data was obtained by plotting $\frac{y_1 \Delta\rho_1}{Y_1 \Delta\rho_{1m}}$ and $\frac{y_2 \Delta\rho_2}{Y_2 \Delta\rho_{2m}}$ against $\frac{v_1}{V}$ and $\frac{v_2}{V}$, respectively, where:

$\Delta\rho_1$ = density difference of fluid between the elevations of the maximum velocity and the corresponding local velocity v_1 , g/cc

$\Delta\rho_2$ = density difference of fluid between the elevations of the maximum velocity and the corresponding local velocity v_2 , g/cc

$\Delta\rho_{1m}$ = density difference of fluid between the elevations of the maximum velocity and the lower limit of the zone of withdrawal, g/cc

$\Delta\rho_{2m}$ = density difference of fluid between the elevations of the maximum velocity and the upper limit of the zone of withdrawal, g/cc

This approach not only satisfied all of the test data, but also made the upper and lower sections of the dimensionless plot symmetrical about the axis, $\frac{v}{V} = 0$. The data are plotted in plate 6 and are satisfied by a parabola whose equation is

$$\frac{v}{V} = \left(1 - \frac{y \, \Delta\rho}{Y \, \Delta\rho_m}\right)^2 \qquad (2)$$

This equation can be used to describe both the upper and lower sections of a velocity distribution using the elevation of the maximum velocity as the reference elevation.

18. A comparison of the velocity distribution observed during a

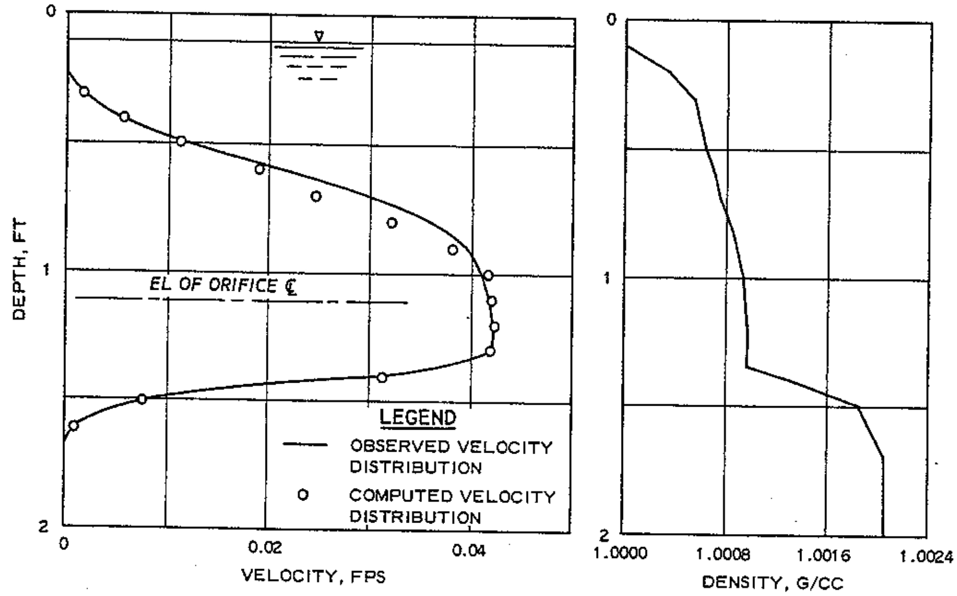

Fig. 7. Comparison of observed and computed velocity distributions for a single test condition

single test and that computed based upon equation 2 is shown in fig. 7. If the limits of the zone of withdrawal, the location of the maximum velocity, and the density profile are known, this procedure can be applied to determine the relative value of the local velocity to the maximum velocity at any vertical position within the zone of withdrawal.

19. However, the need for a method of determining the magnitude of the maximum velocity for any given condition is apparent. Since the magnitude of velocities at a given elevation across the experimental channel appeared to be the same except in the immediate vicinity of the side boundaries, it was assumed that the vertical distribution of velocities is constant throughout the full width of a reservoir. Based upon this assumption, the relation between the average velocity $\overline{V}$ and the maximum velocity V in the zone of withdrawal and across any cross section of a reservoir is expressed as follows:

$$\frac{\overline{V}}{V} = \frac{Q}{AV} = \frac{b\int_0^{Y_1} v_1 \, dy_1 + b\int_0^{Y_2} v_2 \, dy_2}{bHV} \quad (3)$$

where

$\overline{V}$ = the average velocity in the zone of withdrawal, fps

Q = the total discharge through the orifice, cfs

A = cross-sectional area of the zone of withdrawal, sq ft

b = the reservoir width, ft

This can be written as:

$$\frac{\overline{V}}{V} = \frac{1}{H}\left(\int_0^{Y_1} \frac{v_1}{V}\, dy_1 + \int_0^{Y_2} \frac{v_2}{V}\, dy_2\right) \tag{4}$$

Substituting equation 2 into equation 4 yields:

$$\frac{\overline{V}}{V} = \frac{1}{H}\left[\int_0^{Y_1} \left(1 - \frac{y_1\, \Delta\rho_1}{Y_1\, \Delta\rho_{1m}}\right)^2 dy_1 + \int_0^{Y_2} \left(1 - \frac{y_2\, \Delta\rho_2}{Y_2\, \Delta\rho_{2m}}\right)^2 dy_2\right] \tag{5}$$

In order to solve the above integrals, $\frac{\Delta\rho}{\Delta\rho_m}$ must be expressed as a function of $\frac{y}{Y}$. If the density profile is known, this can be easily accomplished. The ratio $\frac{\Delta\rho}{\Delta\rho_m}$ may be several different functions of $\frac{y}{Y}$ in the zone of withdrawal depending upon the density profile; thus, a separate integral must be written for each $\frac{\Delta\rho}{\Delta\rho_m} = f(\frac{y}{Y})$. Each of these integrals can now be evaluated and all added together. Letting the sum of the integrals equal K, the equation can be written as follows:

$$\frac{\overline{V}}{V} = \frac{K}{H} \tag{6}$$

where $\overline{V} = Q/bH$. Then

$$\frac{Q}{bHV} = \frac{K}{H} \tag{7}$$

yielding

$$V = \frac{Q}{bK} \tag{8}$$

It is now possible to determine the upper and lower limits of the zone of withdrawal and the velocity distribution within this zone. This technique is demonstrated in the example presented in Appendix B. In certain cases, the proximity of the free surface and/or bottom boundary may dictate the upper and/or lower limits of the zone of withdrawal. Means for evaluating the conditions under which these boundaries dictate the limits of the withdrawal zone and for determining the distribution of velocities within a zone of withdrawal restricted by boundary conditions are presented in Appendix A. The sample problem (Appendix B) is presented to illustrate application of the results to determine the maximum discharge that may be released through a square orifice for a given set of conditions without exceeding the limits of a desired hypothetical zone of withdrawal, the actual limits of the zone of withdrawal, and the velocity distribution therein. The example also illustrates how the relative contribution of each of several vertical extents or layers to the total release can be determined based upon knowledge of the extent and distribution of velocity within the zone of withdrawal, and then with assumed or known distributions of temperature, dissolved oxygen content, and/or other water quality parameters, how the value of each parameter representative of the total release can be predicted by means of weighted averages.

PART IV: DISCUSSION

20. Although the scope and results obtained in the current studies reported herein are not as comprehensive as desired, a means of predicting the limits of and the velocity distribution within the zone of withdrawal upstream of an orifice has been developed. From these, the relative contribution of selected vertical extents or each layer to the total release can be determined. Then, with assumed or known gradients of temperature, dissolved oxygen content, and/or other water quality parameters, the value of each parameter representative of the total release can be estimated by means of weighted averages. A FORTRAN IV program has been developed and is available in order to make computations on a GE-425 computer. If other pertinent hydrographic data and methodology are known, these results can be applied to predict the effectiveness of proposed selective withdrawal structures and plans of reservoir operation for the preservation and enhancement of water resources.

21. Numerous variables should be evaluated in future research efforts; for example, the effects on selective withdrawal characteristics of the shape and the vertical and horizontal spacing of orifices are desired as well as the width of the orifice relative to the reservoir. Investigations to evaluate the effect of orifice spacing and width of the orifice relative to the reservoir are currently planned. Tests to determine the effect of orifice shape are presently under way. Preliminary observations indicate that the orifice shape has no effect on the withdrawal characteristics for the shapes tested. These included a circular orifice and two rectangular orifices, one with the height twice the width and the other with the width twice the height. The three shapes tested had an area of 0.0256 sq ft, which is equal to the area of the 0.16-ft-square orifice. The relation in plate 4 was modified by replacing the D^2 term with A_o, as shown in plate 7. The data points for the circular and two rectangular orifices as well as a few points for the square orifices are shown plotted in plate 7. This plot indicates that the orifice shape, at least within the limits of the shapes tested, has no effect on the development of the withdrawal limits. It is suggested that plate 7 be used to determine the

withdrawal limits instead of plate 4, since plate 7 is valid for all orifice shapes.

22. Three-dimensional models operated in such a manner that they reproduce typical hydrographic records should be utilized to investigate the effects of unsteady and varied flow conditions due to variations in geometry, inflows, outflows, storage, and density that are characteristic of prototype reservoirs. The results of even limited tests in such models would be most beneficial in the development of mathematical models and computer programs for solution of the problems associated with the planning, design, and operation of reservoirs.

23. Additional studies are desired to investigate model scale effects and the relative importance of viscous effects. These are believed to be most pertinent and are required for development of models and techniques that accurately simulate prototype systems. For example, it appears that similitude of stratified flow systems should be based upon the Froudian criteria, but surely the viscous effects and the Reynolds criteria should be considered so that the fundamental character of flow is the same in both model and prototype. This could be accomplished by reducing the width of the model to increase approach velocities and obtain values of Reynolds numbers comparable to those anticipated in the prototype. However, results of tests in a 1:20-scale, three-dimensional model of the intake structure proposed for New Hope Reservoir agree most favorably with those obtained for the small orifices and generalized study that simulated a single inlet to scales of 1:50 and 1:100.

24. The effect of geometry in the vicinity of an intake structure has been observed to be significant based on the results of specific model studies. For example, in tests of the 1:20-scale, three-dimensional model of the structure proposed for New Hope Reservoir, the model indicated that an inlet located on the upstream face would permit releases approximately double that permitted through a side inlet without initiating withdrawal below the interface or thermocline. Stratified flow patterns observed in the 1:40-scale, three-dimensional model of the outlet works proposed for Meramec Park Reservoir, which reproduced approximately 400 to 500 ft of the reservoir topography and a curved, narrow approach channel upstream of a

single-level intake, indicated local geometry to be of importance also. The narrow approach channel and shallow depth of the reservoir created shear along the interface, which, during high flows, caused considerable turbulence and mixing along the interface. Considerably greater mixing and/or blending of the warm and cold waters would be anticipated with an intake structure located in a relatively shallow, narrow section of a reservoir. The interface tends to be elevated and lowered, respectively, along the inner and outer portions of a curved approach channel. Based upon these observations, the geometry of multiple- and/or single-level intakes and that adjacent to the intakes may have a significant effect upon the withdrawal characteristics.

25. Limited investigations have been conducted to determine the conditions required to initiate withdrawal of a lower, denser fluid over a submerged weir for the purpose of evaluating the effectiveness of such a structure in preventing the release of water from the lower level of a reservoir through a single, low-level intake of a powerhouse or outlet works. A schematic sketch of such facilities which utilized a 1-ft-wide channel and the variables investigated are presented in fig. 8. Test results obtained with two- and three-dimensional models are presented in fig. 9. The three-dimensional model data were obtained from the 1:40-scale model of the vertical-faced weir proposed for construction upstream of the outlet works for Meramec Park Reservoir. The open symbols represent conditions that produced initial and very small quantities of withdrawal. The single solid circle shown in fig. 9 represents a flow condition in which it appeared that a considerable amount of the denser fluid (saline water) was being withdrawn; however, measurement of the volume of saline water withdrawn in a given time indicated that the quantity withdrawn was only about 8 percent of the total discharge released. Additional model tests of a similar weir proposed for construction upstream of the powerhouse intakes in Clarence Cannon Reservoir in which the quantity of saline water withdrawn was determined by the dilution method indicated that the ratio of the quantity of denser fluid withdrawn to that of the total flow was a function of the ratio of the actual to the limiting densimetric Froude number as shown in fig. 10. These limited data indicate that the denser fluid comprises only

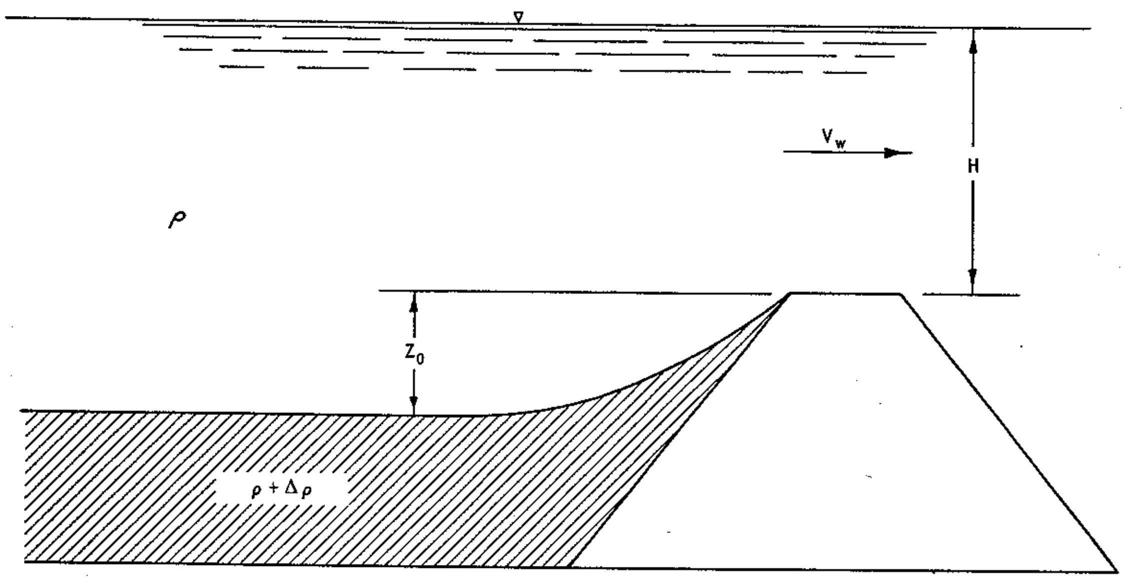

Fig. 8. Weir facilities

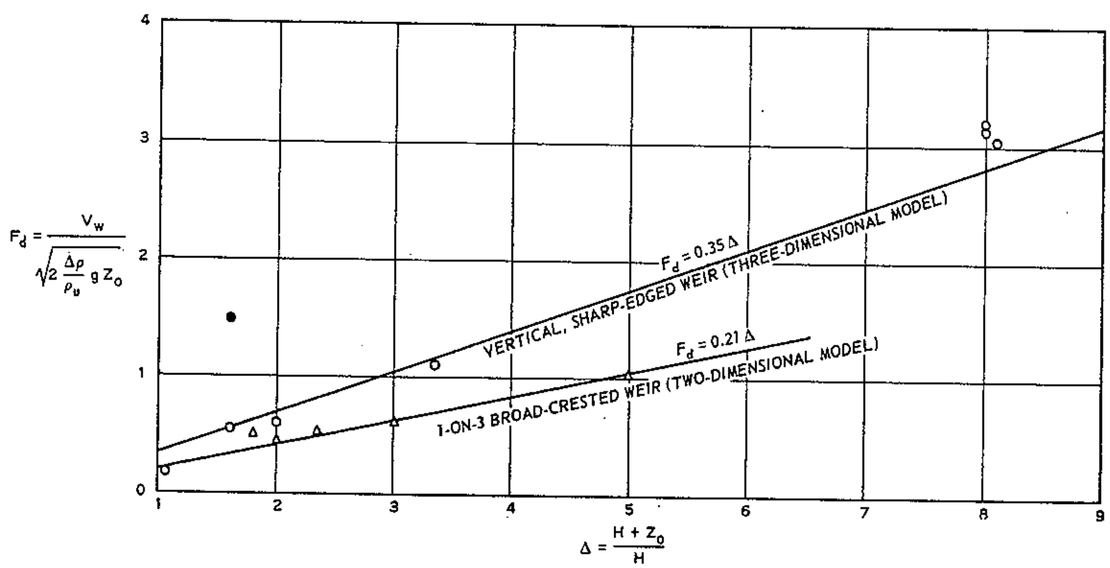

Fig. 9. Withdrawal characteristics of weirs

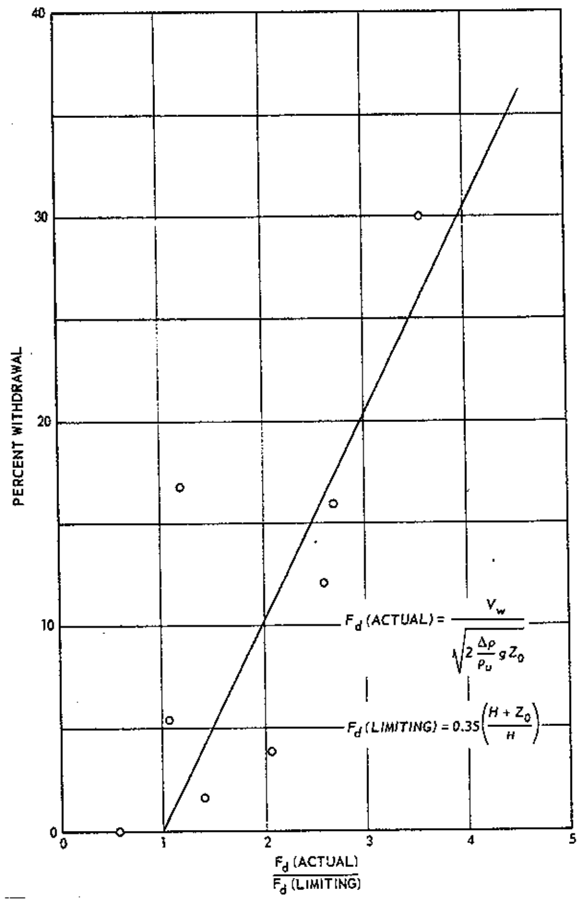

Fig. 10. Quantity of dense fluid withdrawn relative to total released over a vertical, sharp-edged weir

about 10 and 20 percent of the total flow for conditions where the actual densimetric Froude number and/or velocity over the weir are double and triple, respectively, the limiting value at which withdrawal is initiated.

26. In conclusion, it is considered that the use of hydraulic models to evaluate the effectiveness of specific proposed structures should be encouraged to ensure reasonably adequate and accurate performance of proposed projects as well as to gain additional knowledge concerning the mechanics of stratified flow and refinement of the state-of-the-art.

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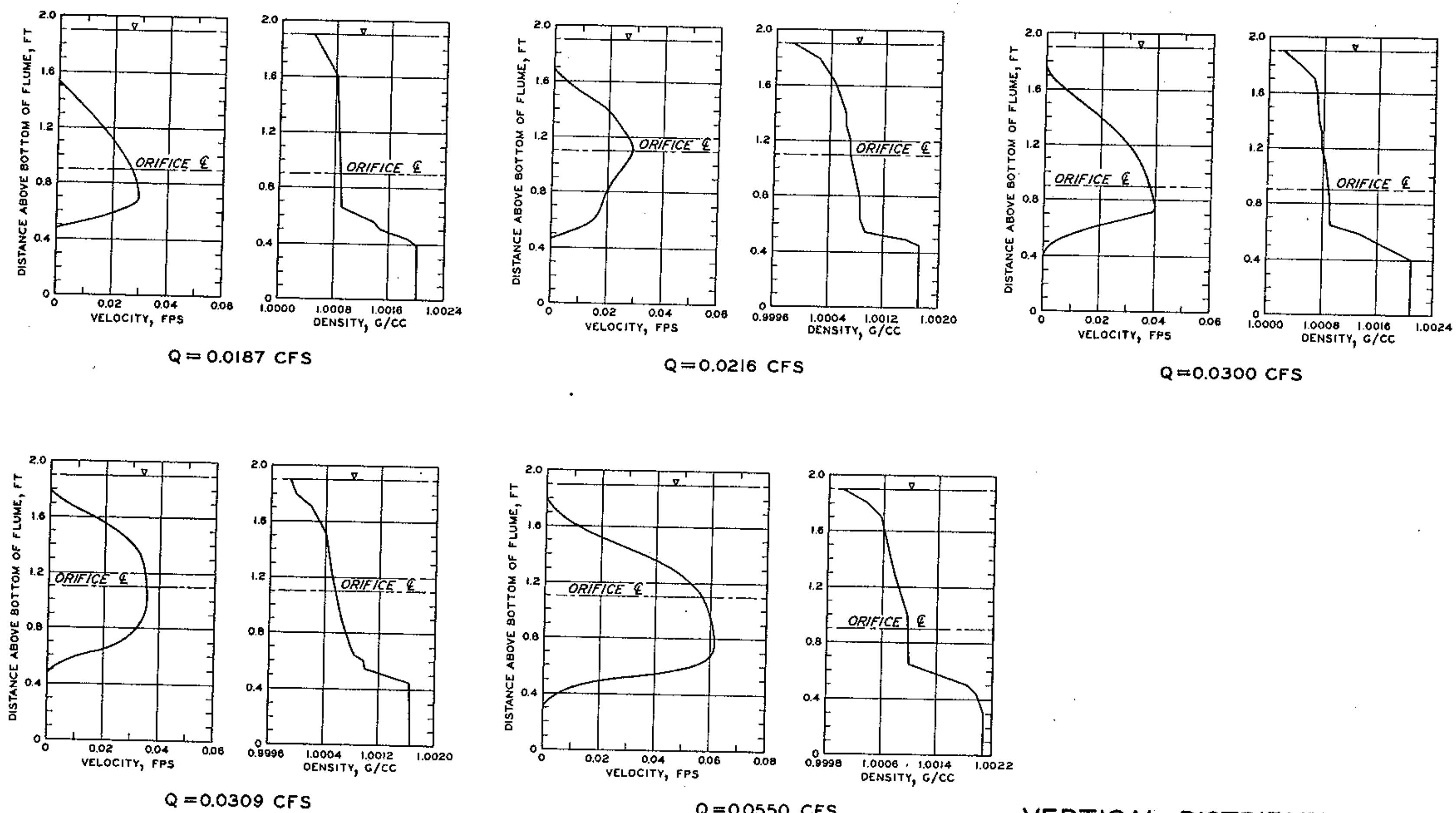
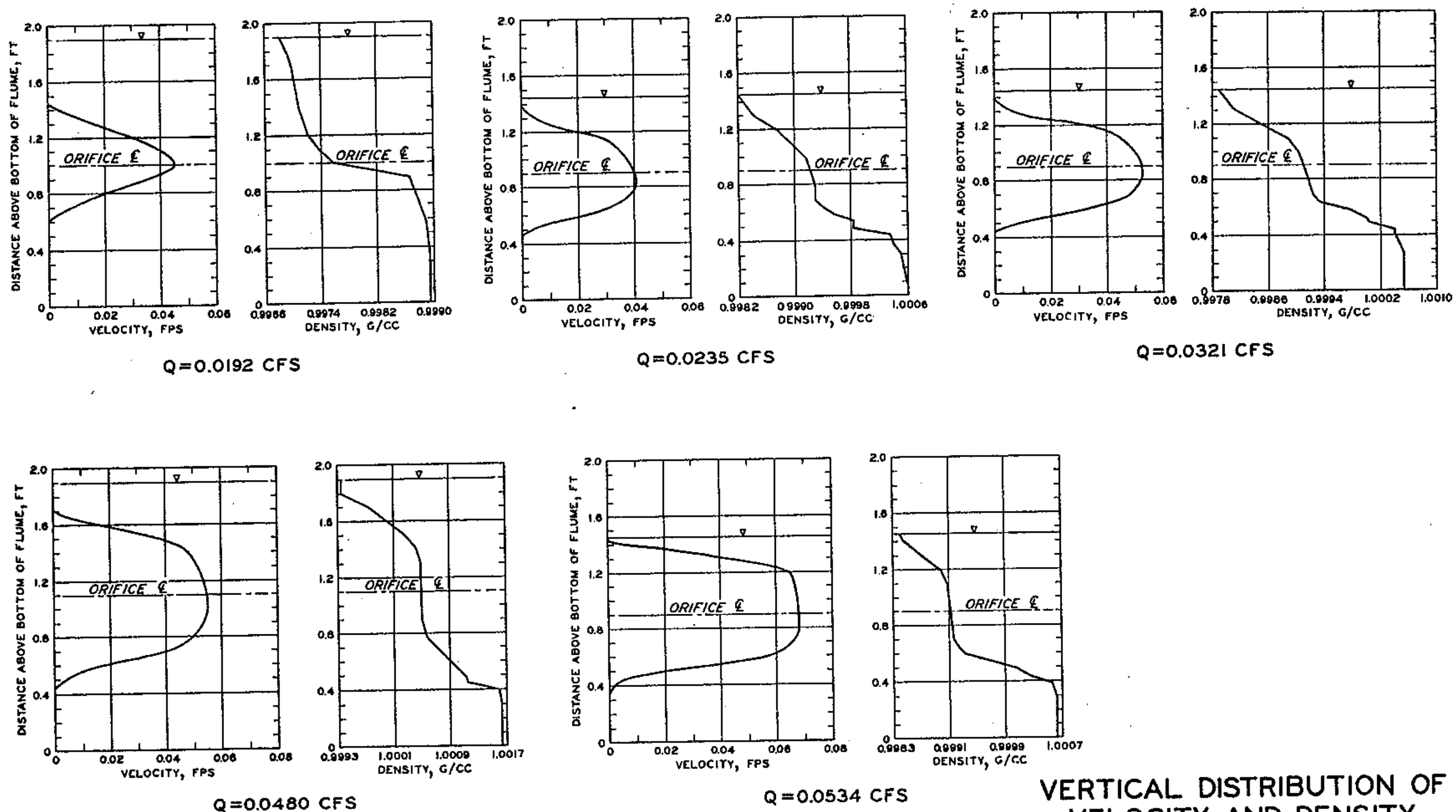


VERTICAL DISTRIBUTION OF VELOCITY AND DENSITY

0.16-FT-SQUARE ORIFICE

Q=0.0187 – 0.0550 CFS



VERTICAL DISTRIBUTION OF VELOCITY AND DENSITY

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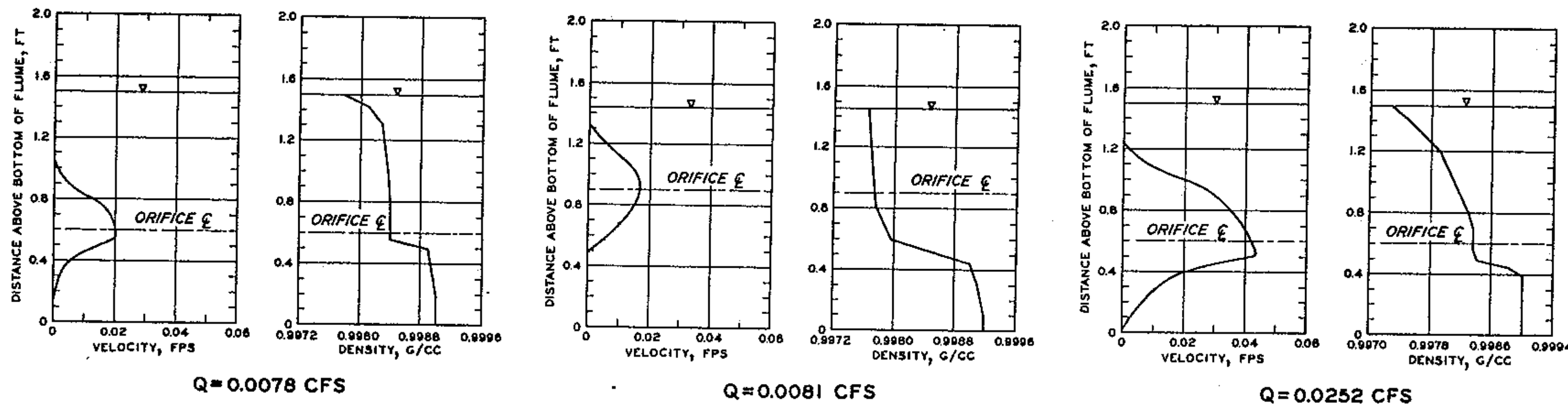
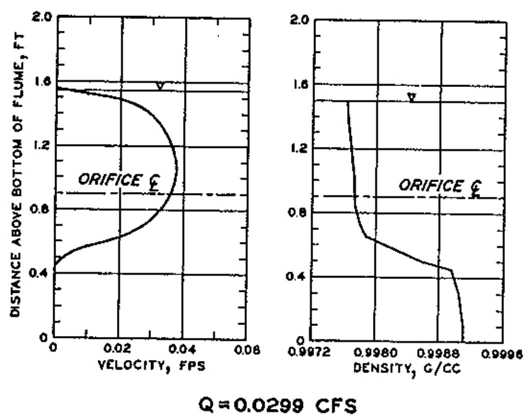
PLATE 2





VERTICAL DISTRIBUTION OF VELOCITY AND DENSITY

0.08-FT-SQUARE ORIFICE

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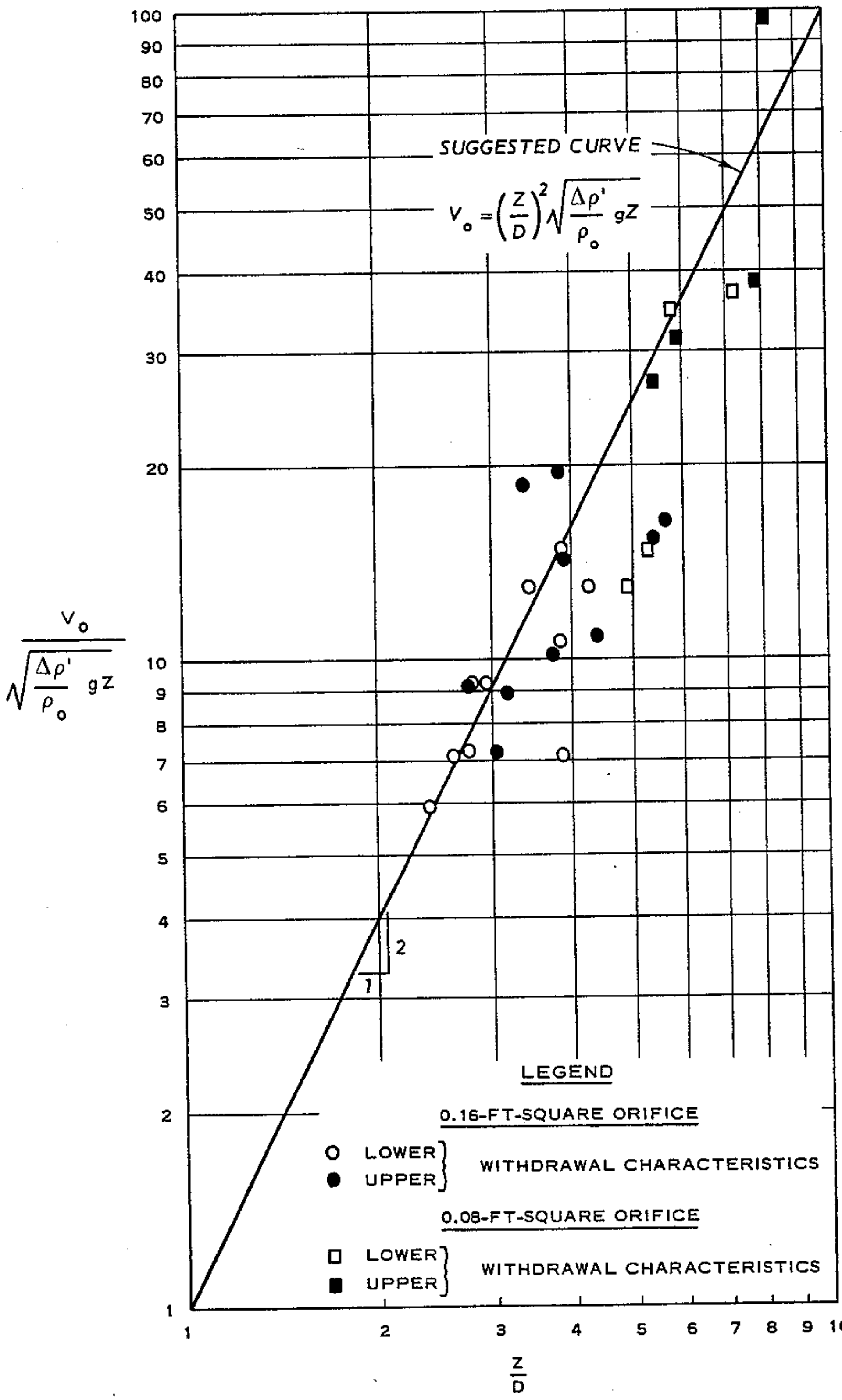
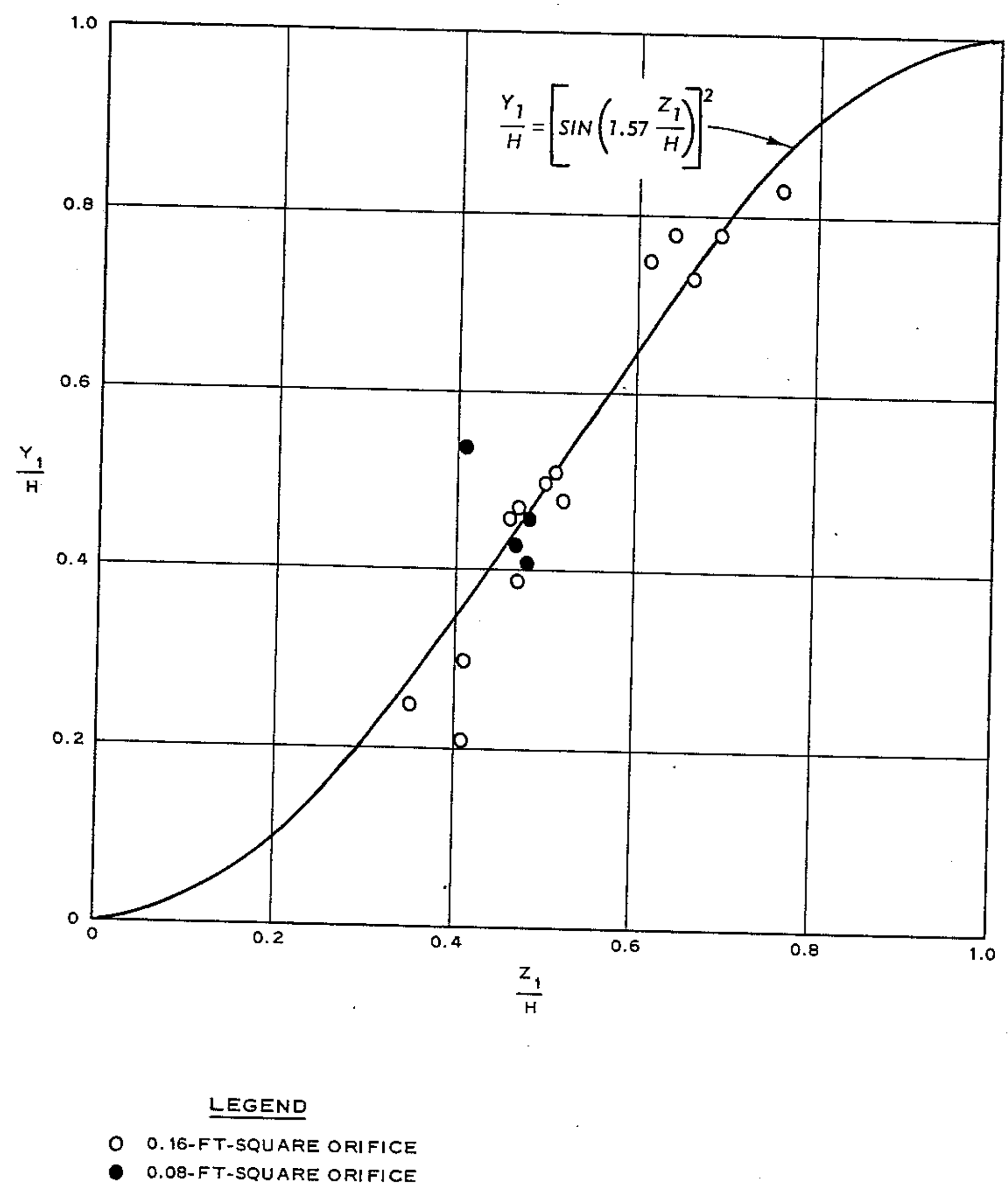
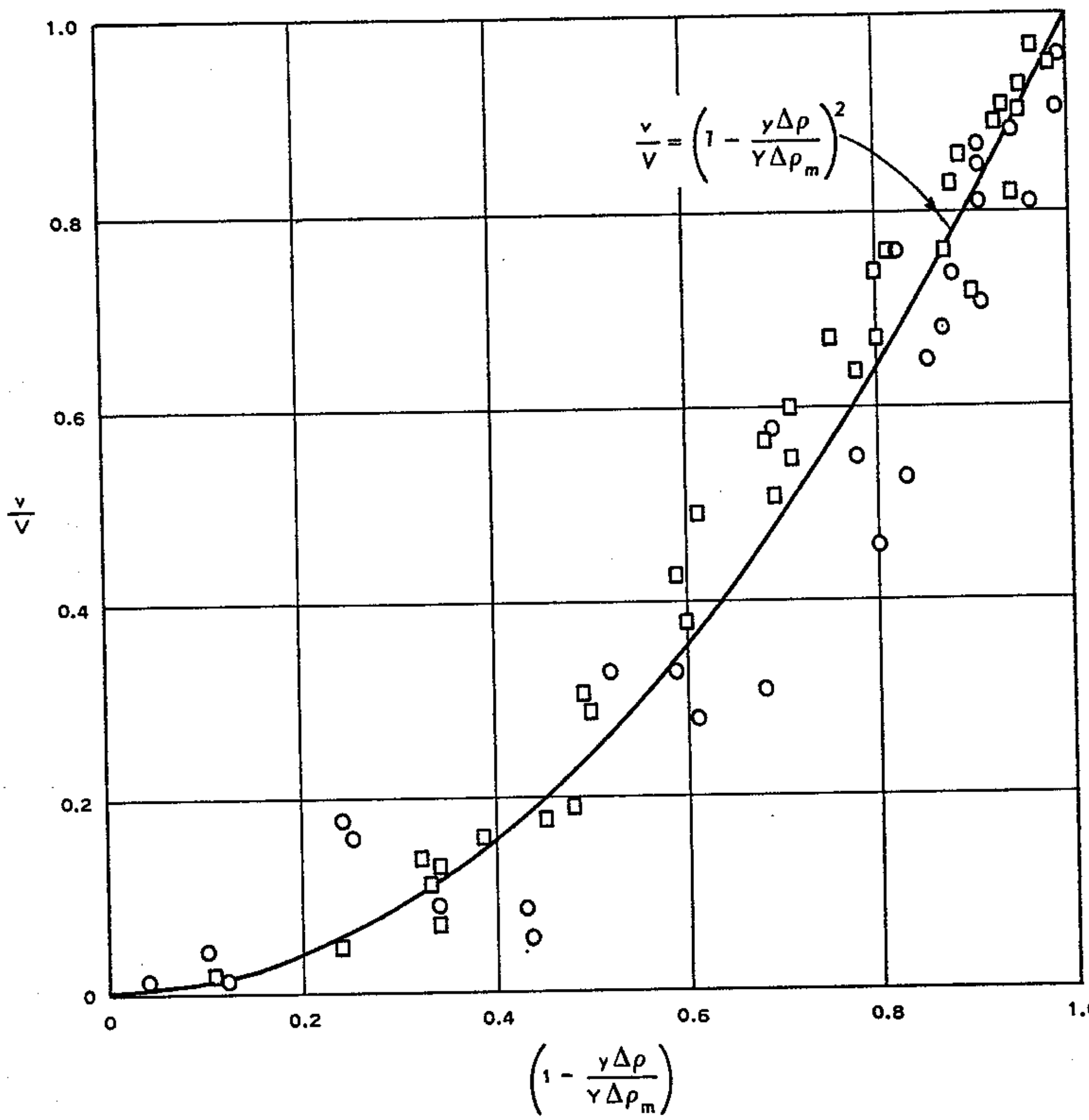


WITHDRAWAL CHARACTERISTICS OF SQUARE ORIFICES



RELATIVE POSITION
OF MAXIMUM VELOCITY

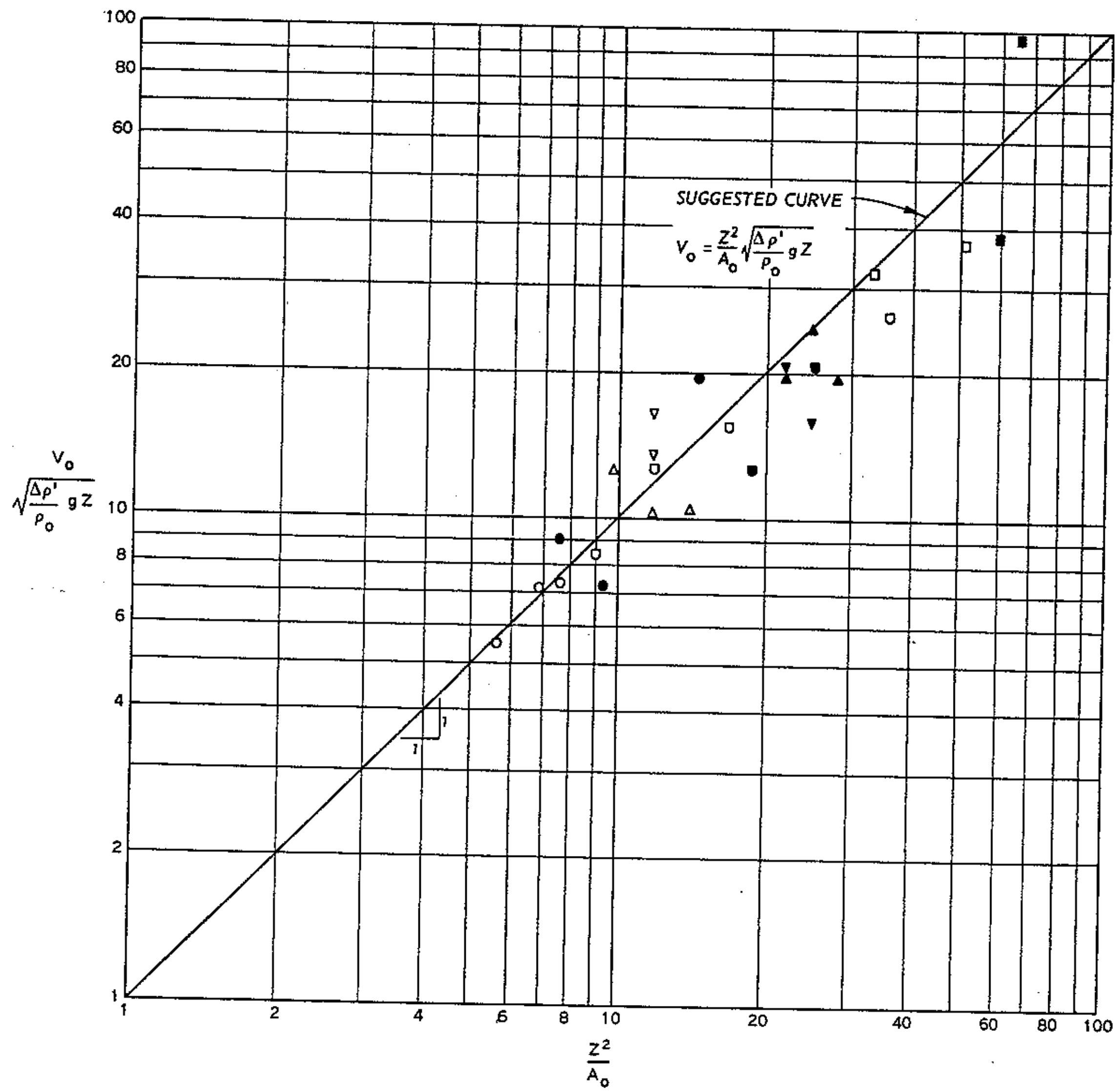


LEGEND

- ○ BELOW ELEVATION OF MAXIMUM VELOCITY
- □ ABOVE ELEVATION OF MAXIMUM VELOCITY

VELOCITY DISTRIBUTION IN STRATIFIED FLOW

BOUNDARY EFFECTS NEGLIGIBLE



LEGEND

0.08-FT-SQUARE ORIFICE

□ LOWER, ■ UPPER } WITHDRAWAL CHARACTERISTICS

0.16-FT-SQUARE ORIFICE

○ LOWER, ● UPPER } WITHDRAWAL CHARACTERISTICS

0.11- BY 0.23-FT RECTANGULAR ORIFICE (LONG AXIS VERT)

▽ LOWER, ▼ UPPER } WITHDRAWAL CHARACTERISTICS

0.11- BY 0.23-FT RECTANGULAR ORIFICE (LONG AXIS HORIZ)

△ LOWER, ▲ UPPER } WITHDRAWAL CHARACTERISTICS

0.18-FT-DIAM ORIFICE

◘ LOWER, ◙ UPPER } WITHDRAWAL CHARACTERISTICS

WITHDRAWAL CHARACTERISTICS OF ORIFICES

APPENDIX A: ANALYSIS OF FREE SURFACE AND BOTTOM BOUNDARY EFFECTS

Introduction

1. In many cases it is desirable to locate an orifice relatively close to the free surface or bottom boundary of a reservoir, which may cause the zone of withdrawal to extend to these boundaries. During the testing program, conditions were encountered in which the free surface controlled the upper limit of the withdrawal zone and the data of these tests were analyzed independent of those previously reported in the main text. The vertical distribution of velocity and density for these particular tests is shown in plate A1. The technique for determining the limits of the zone of withdrawal and the velocities within this zone, presented in the main text, is not valid for these conditions. A method for determining whether the free surface controls the upper limit of the withdrawal zone and for calculating the velocity distribution for such conditions follows.

Data Analysis

2. For conditions of free surface control, Z_2 and $\Delta\rho_2'$ are fixed by the presence of the free surface. The densimetric Froude numbers, for the tests conducted, were calculated using these restricted values and plotted against the ratio Z/D, as shown in plate A2. The points fall to the left of the suggested curve, and an examination of the parameters shows that restricting Z_2 will cause this effect. This provides a method for determining whether or not the withdrawal zone extends to the free surface in a prototype situation. A point can be plotted on the graph of plate A2 by using the distance from the orifice center line (℄) to the free surface and the corresponding density difference. A point that falls to the left of the suggested curve indicates that Z_2 is being restricted, and thus, the withdrawal zone does extend up to the free surface. A point that falls to the right of the suggested curve indicates that the withdrawal zone does not extend up to the free surface and that the technique

developed in the main text of this report can be used. This technique can also be used if the point falls on the suggested curve. This condition indicates that Z_2 is not being restricted, but that the distance from the orifice ℄ to the free surface and the corresponding fluid density difference are the quantities controlling the limit of the zone of withdrawal above the orifice ℄. Thus, a check is provided to determine whether or not the free surface affects the upper limit of the zone of withdrawal.

The elevation of the maximum velocity observed during the tests in which the free surface controlled the upper limit of the withdrawal zone satisfies the relation developed in the main text and shown in plate 5. This plot can be used to determine the elevation of the maximum velocity for conditions in which the zone of withdrawal is not affected by the free surface as well as those in which the free surface controls the upper limit of this zone.

4. The velocity profiles observed during the tests in which the free surface controlled the upper limit of the withdrawal zone were not satisfied by the dimensionless velocity distribution curve developed for conditions in which there was no boundary effect. The most satisfactory fit of the experimental data for conditions of free surface control was found by plotting $1 - \frac{v}{V}$ versus $\frac{y \, \Delta\rho}{Y \, \Delta\rho_m}$, as shown in plate A3. This provides a means of determining the ratios $\frac{v}{V}$ for conditions in which the withdrawal zone extends to the free surface. The maximum velocity V can be determined for any condition by the method presented in the main text. Once the magnitude of V is determined, the local velocities can be found.

Discussion

5. This procedure provides a method of determining whether or not the zone of withdrawal extends up to the free surface and, if so, a means of determining the velocity distribution above the elevation of maximum velocity. There are undoubtedly a number of degrees of free surface effect on the upper limit of the withdrawal zone. These different degrees

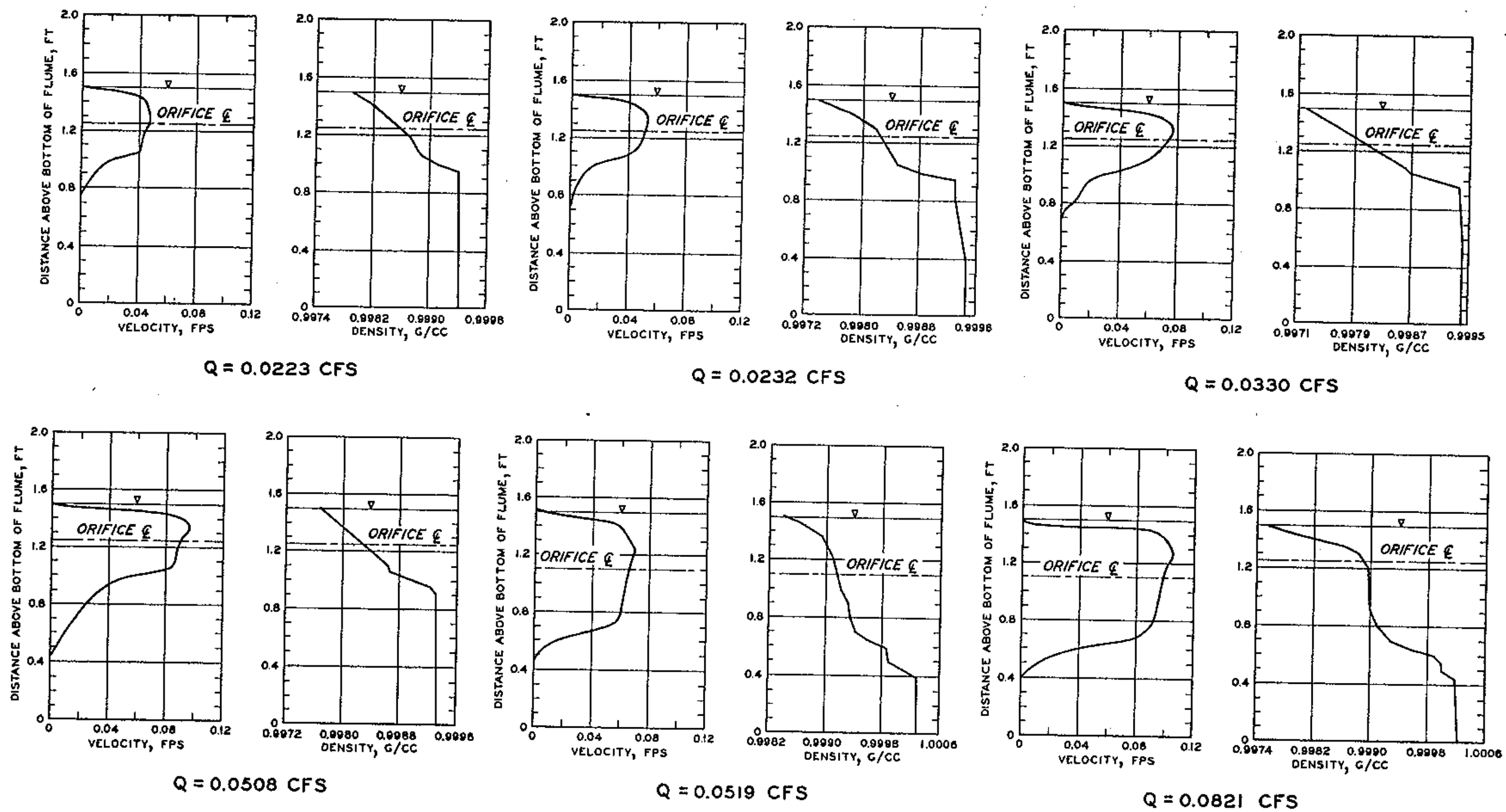
of effect will probably produce slightly different velocity distributions; however, it is felt that the procedure outlined in this appendix will give a good approximation of the actual velocity distributions for these different conditions. The technique presented in this appendix can be used for orifice shapes other than a square, within the range of shapes tested, by replacing D^2 with A_o in the relation in plate A2.

6. Analysis revealed that, for the conditions in which the free surface controlled the upper limit, the location of the lower limit of the withdrawal zone could still be determined by the suggested curve in plate A2. The velocity distributions from the elevation of the maximum velocity to the lower limit in these cases were found to satisfy the dimensionless velocity distribution curve in plate 6 (of main text). This indicated that the lower portion of flow from the stratified system was developed independent of the upper portion.

7. No tests were conducted in which the zone of withdrawal extended down to the bottom boundary. This condition would be similar to the condition in which the free surface controlled the upper limit of the withdrawal zone, in that the distance Z_1 would be restricted by the presence of the bottom boundary. It is believed that the procedure developed in this appendix can be used to determine whether or not the withdrawal zone extends down to the bottom boundary, and if so, to determine the velocity distribution for the flow below the elevation of maximum velocity. This procedure, although unproved, will give an approximation of the actual velocity distribution for this condition until a better technique is developed.

8. The information presented in this appendix is of a preliminary nature. It is presented in this preliminary form because of the urgent need for such design guidance by the district offices of the Corps of Engineers. Some of the information is purely engineering judgment from knowledge acquired from observations made during conduct of the model tests. This information can be verified or disproved with further studies; however, until that time, it will serve as a guide in approximating velocity profiles for conditions in which the free surface or bottom boundary limits the zone of withdrawal.

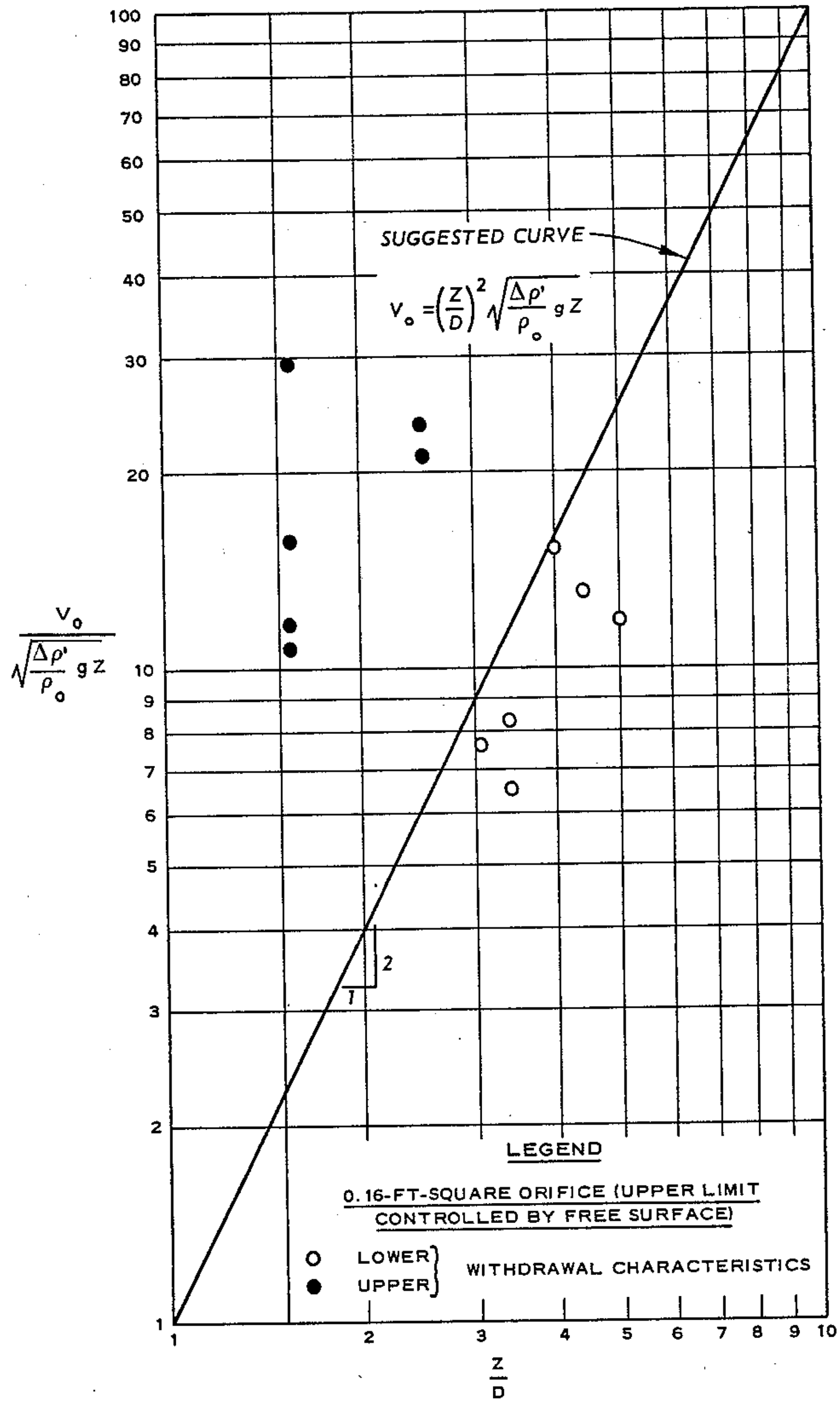
9. For orifice shapes other than a square, plate A2 should be replaced by plate 7 of the main text.



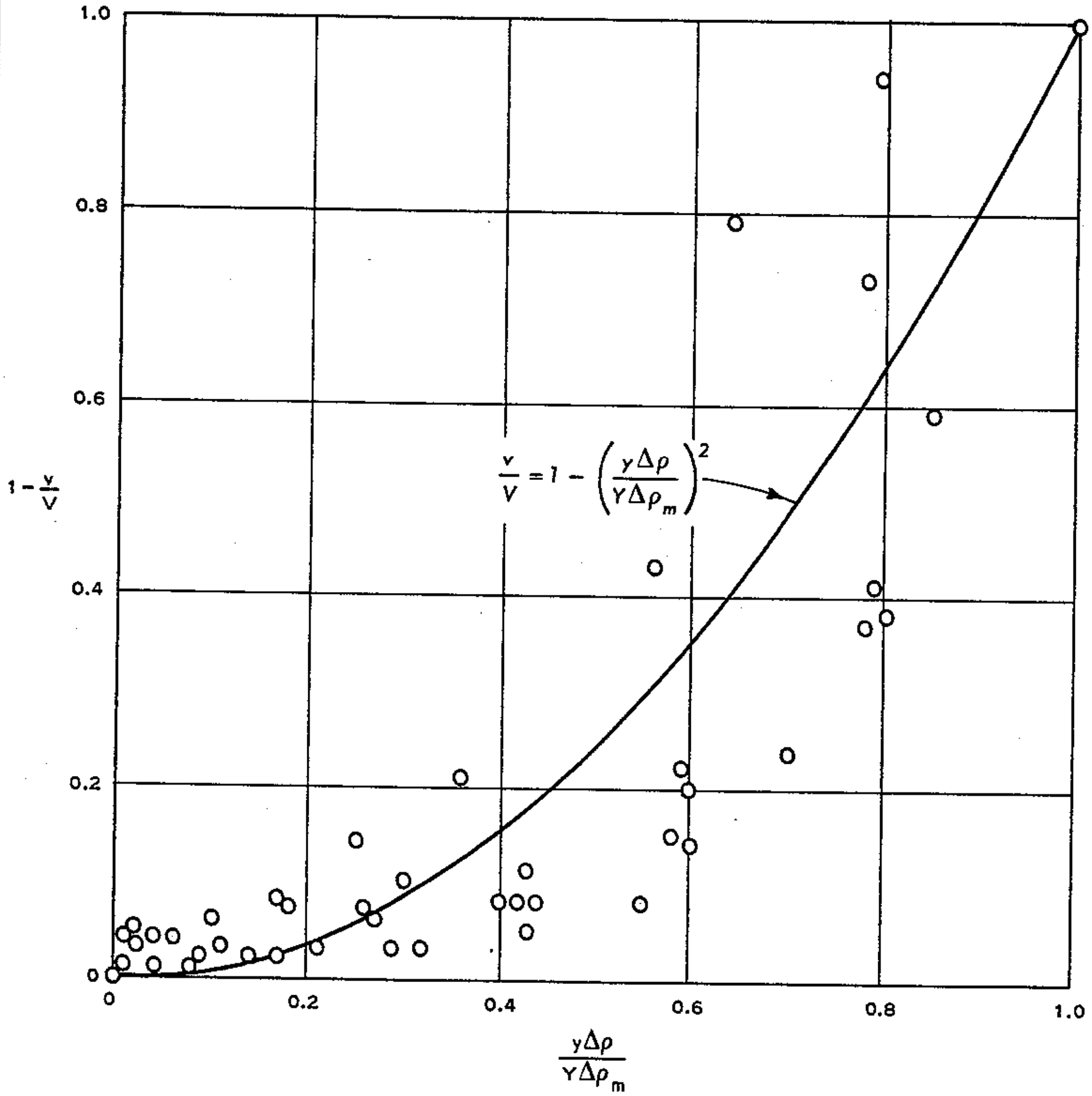
VERTICAL DISTRIBUTION OF VELOCITY AND DENSITY

0.16-FT-SQUARE ORIFICE

Q = 0.0223 - 0.0821 CFS



WITHDRAWAL CHARACTERISTICS OF SQUARE ORIFICE



DIMENSIONLESS VELOCITY DISTRIBUTION IN STRATIFIED FLOW FOR CONDITIONS IN WHICH A BOUNDARY LIMITS THE WITHDRAWAL ZONE

APPENDIX B: SAMPLE PROBLEM

1. The sample problem presented is one in which the orifice size, orifice elevation, and profiles of density and dissolved oxygen content are known and the limits of the withdrawal zone are selected. The unknown quantities are the discharge and the dissolved oxygen content of the outflow. The orifice size and elevation and the profiles of density and dissolved oxygen were chosen to illustrate the technique and may be unrealistic. However, any combination of these parameters can be handled in the same manner.

Problem

2. An 8-ft-square orifice is located 60 ft below the water surface of a reservoir, which has density and dissolved oxygen profiles as shown in figs. B1 and B2. The desired upper and lower limits of the zone of withdrawal are at el 140 and 75, respectively. Determine the maximum allowable discharge that can be withdrawn through the orifice without exceeding the desired limits of the withdrawal zone for a reservoir section 100 ft wide. Also, determine the velocity distribution within the zone of withdrawal and the dissolved oxygen content of the outflow.

Given quantities:

$Z_1 = 25$ ft

$Z_2 = 40$ ft

$D = 8$ ft

$A_o = 64$ sq ft

$g = 32.2$ ft/sec^2

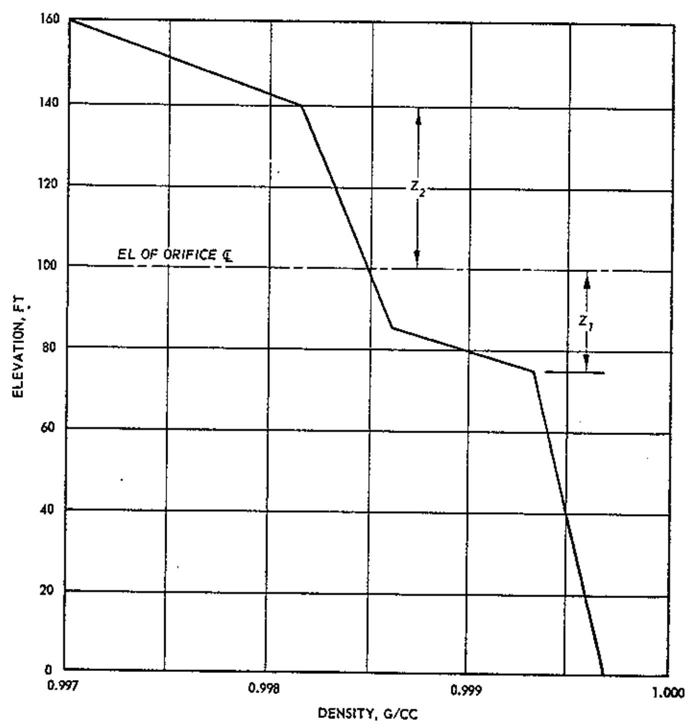


Fig. B1. Density profile

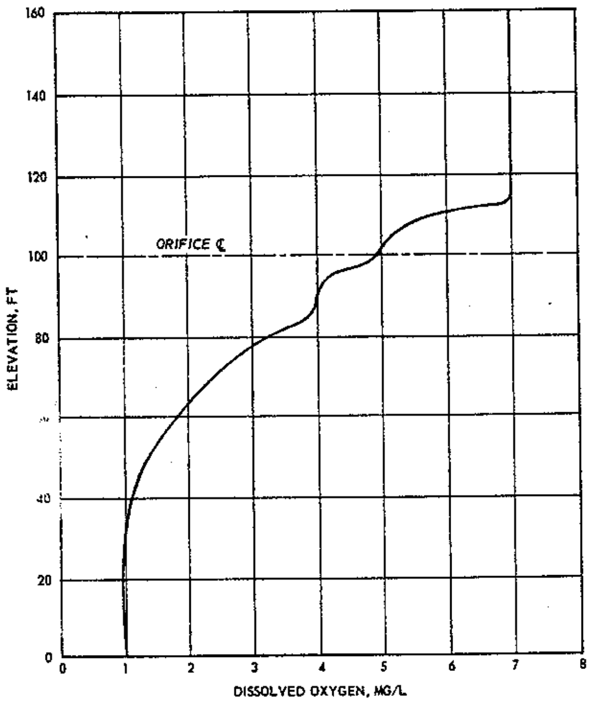


Fig. B2. Dissolved oxygen profile

Quantities obtained from the density profile:

$$\rho_o = 0.99850 \text{ g/cc}$$
$$\Delta\rho_1' = 0.00080 \text{ g/cc}$$
$$\Delta\rho_2' = 0.00035 \text{ g/cc}$$

Solution

3. The first objective is to determine the maximum average velocity that may exist through the orifice without withdrawing beyond the desired limits of the withdrawal zone. This is done by computing the allowable velocity first for the lower limit and then for the upper limit. These two velocities are compared and the lower of the two is designated the controlling velocity, since if the higher velocity was used, the withdrawal zone would extend beyond one of the desired limits. Equation 1 of the main text is used to determine these allowable velocities.

$$V_o = \left(\frac{Z_1}{D}\right)^2 \sqrt{\frac{\Delta\rho_1'}{\rho_o} gZ_1} = \left(\frac{25}{8}\right)^2 \sqrt{\frac{0.0008}{0.9985}(32.2)(25)} = 7.9 \text{ fps}$$

$$V_o = \left(\frac{Z_2}{D}\right)^2 \sqrt{\frac{\Delta\rho_2'}{\rho_o} gZ_2} = \left(\frac{40}{8}\right)^2 \sqrt{\frac{0.00035}{0.9985}(32.2)(40)} = 16.8 \text{ fps}$$

The controlling velocity is therefore 7.9 fps. The allowable discharge through the orifice can now be determined from the equation of continuity.

$$Q = AV$$

$$Q = 64 \text{ sq ft} \times 7.9 \text{ fps} = 506 \text{ cfs}$$

4. Since the allowable velocity for Z_2 was not used, it is

necessary to compute the actual Z_2 for the controlling velocity. Now the unknown quantities in equation 1 are Z_2 and $\Delta\rho_2'$, and these are separated to one side of the equation. The known quantities are substituted into the equation, and a value is obtained as shown below. Then a trial-and-error procedure is used to determine Z_2 by selecting a Z_2 and determining the corresponding $\Delta\rho_2'$ from the density profile. This is illustrated below.

$$V_o = \left(\frac{Z_2}{D}\right)^2 \sqrt{\frac{\Delta\rho_2'}{\rho_o} gZ_2}$$

$$Z_2^5 \Delta\rho_2' = \frac{D^4 \rho_o V_o^2}{g} = \frac{(8)^4 (0.9985)(7.9)^2}{32.2} = 7927$$

Try $Z_2 = 28$ ft , $\Delta\rho_2' = 0.000250$ g/cc , $Z_2^5 \Delta\rho_2' = 4300$

Try $Z_2 = 30$ ft , $\Delta\rho_2' = 0.000275$ g/cc , $Z_2^5 \Delta\rho_2' = 6680$

Try $Z_2 = 31$ ft , $\Delta\rho_2' = 0.000280$ g/cc , $Z_2^5 \Delta\rho_2' = 8016$

Use $Z_2 = 31$ ft

The total thickness of the withdrawal zone is now found by adding Z_1 and Z_2.

$$H = Z_1 + Z_2 = 25 + 31 = 56 \text{ ft}$$

5. The elevation of the maximum velocity is found by determining the distance from the elevation of maximum velocity to the lower limit of the withdrawal zone Y_1 from plate 5 of the main text and adding this to the elevation of the lower limit of the withdrawal zone.

$$\frac{Z_1}{H} = \frac{25}{56} = 0.45$$

From plate 5, $\frac{Y_1}{H} = 0.425$, $Y_1 = 24$ ft , $Y_2 = H - Y_1 = 56 - 24 = 32$ ft.

(Elevation of orifice ℄) - (Z_1) = (Elevation of lower limit)

$$100 - 25 = 75 \text{ ft}$$

(Elevation of lower limit) + (Y_1) = (Elevation of maximum velocity)

$$75 + 24 = 99 \text{ ft}$$

6. The relations between $\frac{\Delta\rho}{\Delta\rho_m}$ and $\frac{y}{Y}$ must now be determined in order to solve for the maximum velocity in the zone of withdrawal. This is most easily accomplished by plotting $\frac{\Delta\rho}{\Delta\rho_m}$ versus $\frac{y}{Y}$ for both the upper and lower portions of the flow (see fig. B3). The quantities $\frac{y_1}{Y_1}$, $\frac{y_2}{Y_2}$, $\frac{\Delta\rho_1}{\Delta\rho_{1m}}$, and $\frac{\Delta\rho_2}{\Delta\rho_{2m}}$ are computed using the elevation of maximum velocity as the datum elevation.

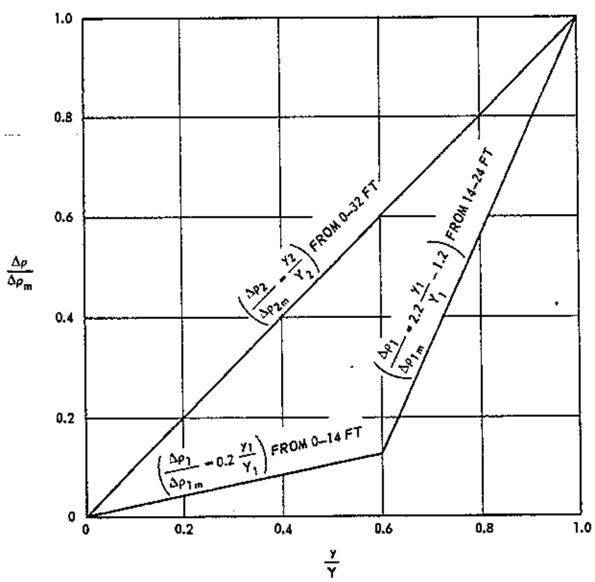


Fig. B3. $\frac{\Delta\rho}{\Delta\rho_m}$ as a function of $\frac{y}{Y}$

7. The relations determined for $\frac{\Delta\rho}{\Delta\rho_m}$ can now be substituted into equation 5 of the main text. Since $\Delta\rho_1/\Delta\rho_{1m}$ is two separate functions of y_1/Y_1 , two integrals must be written between the limits indicated in fig. B3. The maximum velocity in the zone of withdrawal is determined as follows:

$$\frac{\overline{\overline{V}}}{\overline{V}} = \frac{1}{H}\left[\int_0^{Y_1}\left(1 - \frac{y_1\ \Delta\rho_1}{Y_1\ \Delta\rho_{1m}}\right)^2 dy_1 + \int_0^{Y_2}\left(1 - \frac{y_2\ \Delta\rho_2}{Y_2\ \Delta\rho_{2m}}\right)^2 dy_2\right] = \frac{K}{H}$$

Substituting in values of $\Delta\rho/\Delta\rho_m$ as functions of y/Y:

$$K = \int_0^{14}\left(1 - 0.2\frac{y_1^2}{Y_1^2}\right)^2 dy_1 + \int_{14}^{24}\left(1 + 1.2\frac{y_1}{Y_1} - 2.2\frac{y_1^2}{Y_1^2}\right)^2 dy_1$$

$$+ \int_0^{32}\left(1 - \frac{y_2^2}{Y_2^2}\right)^2 dy_2$$

Expanding:

$$K = \int_0^{14}\left(1 - 0.4\frac{y_1^2}{Y_1^2} + 0.04\frac{y_1^4}{Y_1^4}\right) dy_1 + \int_{14}^{24}\left(1 + 2.4\frac{y_1}{Y_1} - 2.96\frac{y_1^2}{Y_1^2}\right.$$

$$\left. - 5.28\frac{y_1^3}{Y_1^3} + 4.84\frac{y_1^4}{Y_1^4}\right) dy_1 + \int_0^{32}\left(1 - 2\frac{y_2^2}{Y_2^2} + \frac{y_2^4}{Y_2^4}\right) dy_2$$

Integrating:

$$K = \left[y_1 - \frac{0.4}{Y_1^2}\left(\frac{y_1^3}{3}\right) + \frac{0.04}{Y_1^4}\left(\frac{y_1^5}{5}\right)\right]\Bigg|_0^{14} + \left[y_1 + \frac{2.4}{Y_1}\left(\frac{y_1^2}{2}\right) - \frac{2.96}{Y_1^2}\left(\frac{y_1^3}{3}\right)\right.$$

$$\left. - \frac{5.28}{Y_1^3}\left(\frac{y_1^4}{4}\right) + \frac{4.84}{Y_1^4}\left(\frac{y_1^5}{5}\right)\right]\Bigg|_{14}^{24} + \left[y_2 - \frac{2}{Y_2^2}\left(\frac{y_2^3}{3}\right) + \frac{1}{Y_2^4}\left(\frac{y_2^5}{5}\right)\right]\Bigg|_0^{32}$$

Applying limits:

$$K = \left[14 - \frac{0.4(14)^3}{(24)^2\,3} + \frac{0.04(14)^5}{(24)^4\,5}\right] + \left[24 + \frac{2.4(24)^2}{(24)\,2} - \frac{2.96(24)^3}{(24)^2\,3} - \frac{5.28(24)^4}{(24)^3\,4}\right.$$

$$\left. + \frac{4.84(24)^5}{(24)^4\,5}\right] - \left[14 + \frac{2.4(14)^2}{(24)\,2} - \frac{2.96(14)^3}{(24)^2\,3} - \frac{5.28(14)^4}{(24)^3\,4} + \frac{4.84(14)^5}{(24)^4\,5}\right]$$

$$+ \left[32 - \frac{2(32)^3}{(32)^2\,3} + \frac{1(32)^5}{(32)^4\,5}\right]$$

Expanding:

$$K = \left[14 - \frac{0.4(2744)}{(576)\,3} + \frac{0.04(537{,}824)}{(331{,}776)\,5}\right] + \left[24 + (2.4)12 - (2.96)8 - (5.28)6\right.$$

$$\left. + (4.84)\,\frac{24}{5}\right] - \left[14 + \frac{2.4(196)}{(24)\,2} - \frac{2.96(2744)}{(576)\,3} - \frac{5.28(38{,}416)}{(13{,}824)\,4} + \frac{4.84(537{,}824)}{(331{,}776)\,5}\right]$$

$$+ \left[32 - \frac{2}{3}(32) + \frac{32}{5}\right]$$

Multiplying:

$$K = (14 - 0.63 + 0.01) + (24 + 28.80 - 23.68 - 31.68 + 23.23)$$

$$- (14 + 9.80 - 4.70 - 3.67 + 1.57) + (32 - 21.33 + 6.40)$$

Reducing:

$$K = 13.38 + 20.67 - 17.00 + 17.07$$

Yielding:

$$K = 34.12$$

Using equation 6 of the main text,

$$\frac{\bar{V}}{V} = \frac{K}{H}$$

where

$$\bar{V} = \frac{Q}{bH}$$

$$V = \frac{Q}{bK} = \frac{506 \text{ cfs}}{100 \text{ ft}(34.12)}$$

$$V = 0.1483 \text{ fps}$$

Knowing V, the local velocities can be determined by using equation 2, as shown in table B1. Note that the elevation of the maximum velocity is used as the datum elevation for determining the values of y_1, y_2, $\Delta\rho_1$, and $\Delta\rho_2$. This yields the vertical distribution of velocities, plotted in fig. B4.

8. Knowing the velocity distribution, it is possible to determine any water quality parameter of the outflow for which a vertical distribution in the reservoir is known. This is demonstrated in table B2 with dissolved oxygen content as the desired water quality parameter. The vertical distribution of dissolved oxygen content in the reservoir is shown in fig. B2. Table B2 also shows the percent discharge from the various layers in the zone of withdrawal.

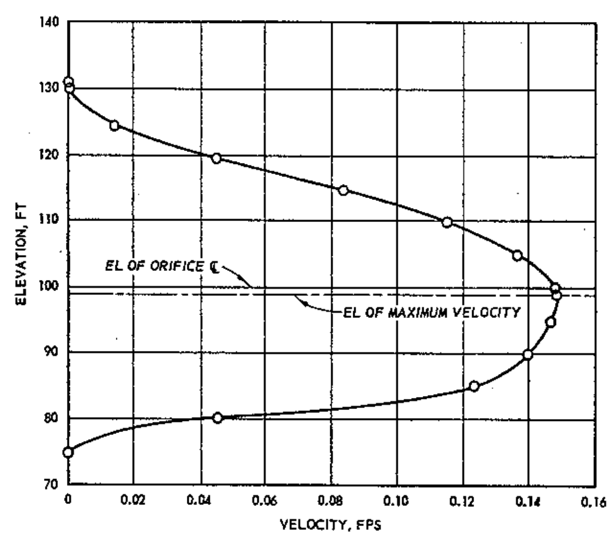


Fig. B4. Vertical distribution of velocity

Table B1

Computation of Local Velocities

El ft	Y ft	$\Delta\rho_m$ g/cc	y ft	$\Delta\rho$ g/cc	$\frac{y\,\Delta\rho}{Y\,\Delta\rho_m}$	$\left(1 - \frac{y\,\Delta\rho}{Y\,\Delta\rho_m}\right)^2$	$v = V\left(1 - \frac{y\,\Delta\rho}{Y\,\Delta\rho_m}\right)^2$
131	32	0.000275	32	0.000275	1	0	0
130	↓	↓	31	0.00027	0.95	0.0025	0.0004
125	↓	↓	26	0.00023	0.68	0.10	0.0148
120	↓	↓	21	0.00019	0.45	0.30	0.0445
115	↓	↓	16	0.00014	0.25	0.56	0.0830
110	↓	↓	11	0.00010	0.12	0.77	0.1142
105	↓	↓	6	0.00006	0.04	0.92	0.1364
100	↓	↓	1	0.00001	0.001	0.998	0.1480
99			Elevation of maximum velocity				0.1483
95	24	0.00079	4	0.00003	0.006	0.99	0.1468
90	↓	↓	9	0.00007	0.03	0.94	0.1394
85	↓	↓	14	0.00012	0.09	0.83	0.1231
80	↓	↓	19	0.00044	0.44	0.31	0.0460
75	↓	↓	24	0.00079	1	0	0

Table B2

Computation of Dissolved Oxygen Content of the Outflow

El ft	Local Velocity V fps	V_{avg} fps	Δ El ft	Width ft	Area A sq ft	$Q = AV_{avg}$ cfs	Q %	Dissolved Oxygen mg/l	Avg Dissolved Oxygen mg/l	$\frac{\%Q \times \text{Avg DO}}{100\%}$
131	0	--	--	--	--	--	--	7	--	--
130	0.0004	0.0002	1	100	100	0.02	0	7	7.0	0
125	0.0148	0.0076	5	↓	500	3.80	1	7	7.0	0.07
120	0.0445	0.0296	5	↓	↓	14.80	3	6	6.5	0.20
115	0.830	0.0638	5	↓	↓	31.90	6	5	5.5	0.33
110	0.1142	0.0986	5	↓	↓	49.30	10	5	5.0	0.50
105	0.1364	0.1253	5	↓	↓	62.65	13	4	4.5	0.58
100	0.1480	0.1422	5	↓	↓	71.10	14	4	4.0	0.56
99	0.1483	0.1482	1	↓	100	14.82	3	4	4.0	0.12
95	0.1468	0.1476	4	↓	400	59.04	12	4	4.0	0.48
90	0.1394	0.1431	5	↓	500	71.55	14	3	3.5	0.49
85	0.1231	0.1312	5	↓	↓	65.60	13	3	3.0	0.39
80	0.0460	0.0846	5	↓	↓	42.30	9	2	2.5	0.22
75	0	0.0230	5	↓	↓	11.50	2	2	2.0	0.04

Q_{total} = 498.38   Dissolved oxygen of outflow = 3.98

APPENDIX C: COMPUTER PROGRAM

Introduction

1. The computations required for analyzing the withdrawal characteristics of flow from a randomly density-stratified reservoir through a submerged orifice, by the method presented in this report, are simple but tedious. If this method is to be used for analysis, a computer program is recommended. The program described herein is comprehensive and can be simplified if computer storage is limited. It is believed that a comprehensive program could be used effectively by those who have a sufficient amount of storage, whereas those who have a limited amount of storage can either gain access to a larger computer, simplify this program, or use this program as a guide for developing a simpler program. This approach was taken because it is the author's understanding that all of the districts and divisions within the Corps of Engineers will eventually have access to a computer with a storage capacity equal to or greater than the facilities at WES. This program has been run successfully on the GE-425 computer at WES. A list of symbols used in the program (fig. C1), a program listing (fig. C2), and a flow chart (fig. C3) are included in this appendix, as well as a sample input sheet (fig. C4) and a sample output listing (fig. C5).

Description of Program

2. This program can be used to solve three different approaches to the problem of selective withdrawal: (1) the withdrawal limits and the orifice size and elevation are known and the discharge is unknown; (2) the discharge and the orifice size and elevation are known and the withdrawal limits are unknown; and (3) the withdrawal limits and the orifice size are known and the discharge and orifice elevation are unknown. The three approaches will be referred to as conditions (1), (2), and (3), respectively, and will be described in more detail later.

3. The first part of the program consists of a conversion scheme for

converting temperature (^{o}F) to temperature (^{o}C) and temperature (^{o}C) to density (g/cc) and an interpolation scheme for interpolating to every foot the dissolved oxygen contents, temperatures, and in some cases densities, which are provided as input. The final product of these schemes is a two-dimensional table consisting of density, temperature (^{o}C), and dissolved oxygen content at every foot of elevation. Control is then shifted to one of three locations within the program to solve either condition (1), (2), or (3).

4. Condition (1) is the approach used to solve the sample problem in Appendix B. An average velocity through the orifice is determined first using the lower limit of the withdrawal zone as the control and then using the upper limit as the control. The lower of these two velocities is multiplied by the orifice area to give the maximum allowable discharge through the orifice. The withdrawal limit corresponding to the higher of these two velocities must be adjusted to agree with the computed maximum allowable discharge. Of course, in some cases the two velocities will be equal and therefore no adjustment will be required. Once the withdrawal limits are established, the velocity profile within the zone of withdrawal is calculated. The weighted average technique is then applied to the velocity profile to determine the density, temperature, and dissolved oxygen content of the outflow.

5. Condition (2) is used when the discharge is selected, the orifice size and elevation are known, and the withdrawal limits must be calculated. This condition presents an added problem. Since the withdrawal limits are not selected, as they are for the other two conditions, it is possible that the withdrawal zone may extend to the free surface and/or the bottom boundary. Under these conditions the velocity profile must be modified as discussed in Appendix A. The program determines whether or not the withdrawal zone extends to the free surface and/or bottom boundary and, if so, uses the method described in Appendix A to calculate the velocity profile. If the withdrawal zone does not extend to the boundaries, the procedures described in the main text are used to determine the withdrawal limits and to compute the velocity profile. In some cases the withdrawal zone may extend to the free surface and not to the bottom boundary or vice versa; in such

cases, half of the velocity profile is computed using the technique in Appendix A and the other half using the technique in the main text. Once the velocity profile is computed, the weighted average technique is applied to determine the density, temperature, and dissolved oxygen content of the outflow.

6. Condition (3) provides a solution when the withdrawal limits and orifice size are selected. A trial-and-error procedure places the orifice at an elevation within the withdrawal zone at which the withdrawal zone extends just to the selected withdrawal limits. The discharge is determined for the orifice ℄ at this elevation. The velocity profile is then computed and the weighted average technique applied to it to determine the density, temperature, and dissolved oxygen content of the outflow.

Input Data

7. Two cards of 80 characters each are provided for a description of the particular problem. A third data card contains the following parameters, with the numbers in parentheses indicating the columns in which the parameter is entered: acceleration due to gravity, ft/sec^2 (1-5); orifice area, sq ft (6-10); orifice ℄ elevation (11-15); reservoir width at the section in question, ft (16-25); water-surface elevation (26-30); elevation of the upper limit of the withdrawal zone (31-40); elevation of the lower limit of the withdrawal zone (41-50); discharge passing through the orifice, cfs (51-60); a number--1, 2, or 3--indicating the condition to be solved (61-65); the number of elevations at which density is input (66-70); the number of elevations at which temperature is input (71-75); and the number of elevations at which dissolved oxygen content is input (76-80). All of these parameters will not be known for every condition. For those parameters which are unknown, a zero should be input. The next input data will be a table of elevation, temperature in degrees Centigrade, and temperature in degrees Fahrenheit. Two rows of this table are input on each card as follows, with the numbers in parentheses indicating the card columns in which the parameter is entered:

CARD NO. 1: $Elev_1$(1-10), Temp C_1(11-20), Temp F_1(21-30),

$Elev_2$(31-40), Temp C_2(41-50), Temp F_2(51-60)

CARD NO. 2: $Elev_3$(1-10), Temp C_3(11-20), Temp F_3(21-30),

$Elev_4$(31-40), Temp C_4(41-50), Temp F_4(51-60)

8. In some cases it may be desirable to input a table of elevation and density and in other cases it may be sufficient to convert the temperatures from the elevation-temperature table to density. This is done in the program with the use of the following equation*:

$$\rho = 1 - \left[\frac{(t - 3.9863)^2}{508,929.2} \cdot \frac{t + 288.9414}{t + 68.12963}\right]$$

where

ρ = density of the fluid, g/cc

t = temperature of the fluid, ^{o}C

The elevation-density table may be omitted by entering a zero for NDEN (the number of elevations at which density is input) on the third data card. If an elevation-density table is used, four pairs of input points are put on each card using the following format:

CARD NO. 1: $Elev_1$(1-10), Den_1(11-20), $Elev_2$(21-30), Den_2(31-40),

$Elev_3$(41-50), Den_3(51-60), $Elev_4$(61-70), Den_4(71-80)

9. A third table of input is required. This has been written into the program as an elevation-dissolved oxygen content table; however, any

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* Leroy W. Tilton and John K. Taylor, "Accurate Representation of the Refractivity and Density of Distilled Water as a Function of Temperature," Research Paper RP971, Journal of Research of the National Bureau of Standards, Vol 18, Feb 1937, pp 205-214.

other water quality parameter for which the value of the outflow is desired may be input in this table. This is the only one of the three tables that can be used for this purpose. The format for this table is the same as that for the elevation-density table.

10. It is important that the first pair of values in each of the tables used as input be the elevation of the water surface and the respective parameter at the water surface. For conditions (1) and (3), the tables should extend at least to the selected lower limit of the withdrawal zone. However, for condition (2), the last pair of values in the input tables must be the elevation of the bottom boundary and the respective parameter at the bottom boundary. This is necessary because condition (2) conducts a check to determine whether the withdrawal zone extends to the bottom boundary. The elevation interval between the input values in the three tables may vary within a table and also between the three tables. The program, as written, allows for input at 20 elevations for each table and a maximum difference between the top and bottom elevations of 300 ft. These limitations can be increased simply by changing the DIMENSIØN statement. One other limitation is that the distance from the orifice ℄ to the upper or lower limit of the withdrawal zone may not exceed 100 ft. This also can be increased by changing the DIMENSIØN statement.

Program Output

11. The program output consists of the program title and two lines of description of the particular problem. The reservoir width, water-surface elevation, and orifice ℄ elevation are given, followed by the orifice area, average velocity through the orifice, and the discharge through the orifice. The upper and lower limits of the withdrawal zone and the elevation of the maximum velocity as well as the maximum velocity within the withdrawal zone are given. If the withdrawal zone extends to the free surface and/or bottom boundary, a statement to this effect is given. The velocity profile within the withdrawal zone is shown as a table of elevation versus velocity. The discharge obtained by integrating the velocity profile is then listed, along with the density, temperature, and dissolved

oxygen content of the outflow. All of the output information is self-explanatory as shown on the sample output sheet in fig. C5.

Sample Problem

12. The sample problem was selected to show a condition in which the withdrawal zone extended to the free surface. The water surface was at el 200 with the orifice ℄ at el 190. The orifice had a cross-sectional area of 64 sq ft and a discharge of 400 cfs. The analysis was made at a reservoir section 1000 ft wide. Assuming that the density profile in the reservoir was unknown, only the elevation-temperature and elevation-dissolved oxygen content tables were input. These input data are shown in the following tabulations:

Elevation	Temperature, °C	Temperature, °F
200	0	78.0
190	0	77.0
180	0	76.0
175	0	74.0
170	0	68.0
165	0	62.0
160	0	58.0
150	0	57.0
100	0	54.0
0	0	46.0

Elevation	Dissolved Oxygen Content, mg/l
200	6.8
170	5.6
150	4.8
60	3.9
0	1.1

Of course, the temperature (°C) is not equal to zero. However, rather than convert temperature (°F) to temperature (°C) by hand, temperature (°C) was input as zero and the computer made the conversion. These input data are shown in the proper format in fig. C4. Fig. C5 is the output listing for this sample problem.

AØ Area of orifice opening, sq ft

AV Maximum allowable velocity through the orifice without exceeding the withdrawal limits, fps

AVDEN1 Average of two densities, 1 ft apart, below the elevation of maximum velocity, g/cc

AVDEN2 Average of two densities, 1 ft apart, above the elevation of maximum velocity, g/cc

AVGDØ1 Average of two dissolved oxygen contents, 1 ft apart, below the elevation of maximum velocity, mg/l

AVGDØ2 Average of two dissolved oxygen contents, 1 ft apart, above the elevation of maximum velocity, mg/l

AVTEM1 Average of two temperatures, 1 ft apart, below the elevation of maximum velocity, °C

AVTEM2 Average of two temperatures, 1 ft apart, above the elevation of maximum velocity, °C

AVZ1 Average velocity through the orifice using lower limit of withdrawal zone as control, fps

AVZ2 Average velocity through the orifice using upper limit of withdrawal zone as control, fps

BTEST AV/ √(DRHØB/RHØØ)*G*ZB

BTRY (ZB**2)/AØ

DEN Average density of fluid flowing into orifice, g/cc

DEN1 Average density of a 1-ft-thick horizontal layer, below the elevation of maximum velocity, times the percent of the total discharge from the layer, g/cc

DEN2 Average density of a 1-ft-thick horizontal layer, above the elevation of maximum velocity, times the percent of the total discharge from the layer, g/cc

DISØXY Average dissolved oxygen content of fluid flowing into orifice, mg/l

DISØX1 Average dissolved oxygen content of a 1-ft-thick horizontal layer, below the elevation of maximum velocity, times the percent of the total discharge from the layer, mg/l

DISØX2 Average dissolved oxygen content of a 1-ft-thick horizontal layer, above the elevation of maximum velocity, times the percent of the total discharge from the layer, mg/l

DRHØB Density difference of fluid between the elevation of the orifice ℄ and the bottom boundary, g/cc

DRHØS Density difference of fluid between the elevation of the orifice ℄ and the free surface, g/cc

Fig. C1. List of symbols (sheet 1 of 5)

DRHØ1	Density difference of fluid between the elevation of the maximum velocity in the withdrawal zone and Y1, g/cc
DRHØ2	Density difference of fluid between the elevation of the maximum velocity in the withdrawal zone and Y2, g/cc
DRHØ1M	Density difference of fluid between the elevation of the maximum velocity in the withdrawal zone and the lower limit of the withdrawal zone, g/cc
DRHØ2M	Density difference of fluid between the elevation of the maximum velocity in the withdrawal zone and the upper limit of the withdrawal zone, g/cc
DRHØ1P	Density difference of fluid between the elevation of the orifice ℄ and the lower limit of the withdrawal zone, g/cc
DRHØ2P	Density difference of fluid between the elevation of the orifice ℄ and the upper limit of the withdrawal zone, g/cc
ELEDEN	Table of elevation and density
ELEDØX	Table of elevation and dissolved oxygen content
ELETEM	Table of elevation, temperature ($^{\circ}C$) and temperature ($^{\circ}F$)
ELEV1	Elevation of Y1
ELEV2	Elevation of Y2
G	Acceleration due to gravity, ft/sec^2
H	Total thickness of withdrawal zone, ft
ICØM	Full line for description of problem
IIØM	Full line for description of problem
KW	Control to set the condition to be solved (1, 2, or 3)
NDEN	Number of elevations at which density is input in ELEDEN table
NDØX	Number of elevations at which dissolved oxygen content is input in ELEDØX table
NTEM	Number of elevations at which temperature is input in ELETEM table
NH	Total thickness of the withdrawal zone rounded off to the nearest foot
NY1M	Distance from the elevation of the maximum velocity in the withdrawal zone to the elevation of the lower limit of the withdrawal zone rounded off to the nearest foot
NZCLØ	Elevation of the orifice ℄ rounded off to the nearest foot
NZLL	Elevation of the lower limit of the withdrawal zone rounded off to the nearest foot
NZMV	Elevation of the maximum velocity in the withdrawal zone rounded off to the nearest foot

Fig. C1 (sheet 2 of 5)

NZUL	Elevation of the upper limit of the withdrawal zone rounded off to the nearest foot
PARAM	Table of density, temperature (^{o}C), and dissolved oxygen content at every foot of depth
PCENQ1	Percent of the total discharge flowing from a 1-ft-thick horizontal layer below the elevation of maximum velocity in the withdrawal zone
PCENQ2	Percent of the total discharge flowing from a 1-ft-thick horizontal layer above the elevation of maximum velocity in the withdrawal zone
Q	Total discharge through the orifice, cfs
Q1	Discharge from a 1-ft-thick horizontal layer below the elevation of maximum velocity in the withdrawal zone, cfs
Q2	Discharge from a 1-ft-thick horizontal layer above the elevation of maximum velocity in the withdrawal zone, cfs
RHØØ	Density of the fluid at the elevation of the orifice ℄, g/cc
RHØVM	Density of the fluid at the elevation of maximum velocity in the withdrawal zone, g/cc
RW	Reservoir width at section in question, ft
SDEN1	Σ DEN1
SDEN2	Σ DEN2
SDØX1	Σ DISØX1
SDØX2	Σ DISØX2
STEM1	Σ TEMP1
STEM2	Σ TEMP2
STEST	AV/ $\sqrt{\text{(DRHØS/RHØØ)*G*ZS}}$
STRY	(ZS**2)/AØ
SUM	SUM1 + SUM2
SUMQ	Total discharge computed from velocity profile (SUM3 + SUM4), cfs
SUM1	$\Sigma \left[1 - \left(\frac{y_1 \Delta\rho_1}{Y_1 \Delta\rho_{1m}}\right)^2\right]$ if the bottom boundary controls the lower limit of the withdrawal zone $\Sigma \left(1 - \frac{y_1 \Delta\rho_1}{Y_1 \Delta\rho_{1m}}\right)^2$ if the bottom boundary does not control the lower limit of the withdrawal zone

Fig. C1 (sheet 3 of 5)

SUM2 $\Sigma \left[1 - \left(\frac{y_2 \Delta\rho_2}{Y_2 \Delta\rho_{2m}}\right)^2\right]$ if the free surface controls the upper limit of the withdrawal zone

$\Sigma \left(1 - \frac{y_2 \Delta\rho_2}{Y_2 \Delta\rho_{2m}}\right)^2$ if the free surface does not control the upper limit of the withdrawal zone

SUM3 Σ Q2

SUM4 Σ Q1

TEMP Average temperature of fluid flowing into orifice, ^oC

TEMP1 Average temperature of a 1-ft-thick horizontal layer, below the elevation of maximum velocity, times the percent of the total discharge from the layer, ^oC

TEMP2 Average temperature of a 1-ft-thick horizontal layer, above the elevation of maximum velocity, times the percent of the total discharge from the layer, ^oC

TEST $A_o^2 \rho_o V_o^2/G$

TRY $Z_1^5 \Delta\rho_1'$ or $Z_2^5 \Delta\rho_2'$

VAVG1 Average of two local velocities 1 ft apart below the elevation of maximum velocity in the withdrawal zone, fps

VAVG2 Average of two local velocities 1 ft apart above the elevation of maximum velocity in the withdrawal zone, fps

VM Maximum velocity in the withdrawal zone, fps

VRA1 $1 - \left(\frac{y_1 \Delta\rho_1}{Y_1 \Delta\rho_{1m}}\right)^2$ if the bottom boundary controls the lower limit of the withdrawal zone

$\left(1 - \frac{y_1 \Delta\rho_1}{Y_1 \Delta\rho_{1m}}\right)^2$ if the bottom boundary does not control the lower limit of the withdrawal zone

VRA2 $1 - \left(\frac{y_2 \Delta\rho_2}{Y_2 \Delta\rho_{2m}}\right)^2$ if the free surface controls the upper limit of the withdrawal zone

$\left(1 - \frac{y_2 \Delta\rho_2}{Y_2 \Delta\rho_{2m}}\right)^2$ if the free surface does not control the upper limit of the withdrawal zone

Fig. C1 (sheet 4 of 5)

V1 Local velocity of fluid at ELEV1, fps

V2 Local velocity of fluid at ELEV2, fps

WS Elevation of water surface, ft

YD1M (Y1M)(DRHØ1M)

YD2M (Y2M)(DRHØ2M)

Y1 Distance from the elevation of maximum velocity in the withdrawal zone to any point between the maximum velocity and the lower limit of the withdrawal zone, ft

Y2 Distance from the elevation of maximum velocity in the withdrawal zone to any point between the maximum velocity and the upper limit of the withdrawal zone, ft

Y1M Distance from the elevation of the maximum velocity in the withdrawal zone to the elevation of the lower limit of the withdrawal zone, ft

Y2M Distance from the elevation of the maximum velocity in the withdrawal zone to the elevation of the upper limit of the withdrawal zone, ft

Y1MH Y1M/H

ZB Vertical distance from orifice ℄ to the bottom boundary, ft

ZCLØ Elevation of orifice ℄, ft

ZLL Elevation of the lower limit of the withdrawal zone, ft

ZMV Elevation of the maximum velocity in the withdrawal zone, ft

ZS Vertical distance from the orifice ℄ to the free surface, ft

ZUL Elevation of the upper limit of the withdrawal zone, ft

Z1 Vertical distance from the orifice ℄ to the lower limit of the withdrawal zone, ft

Z2 Vertical distance from the orifice ℄ to the upper limit of the withdrawal zone, ft

Z1H Z1/H

Fig. C1 (sheet 5 of 5)

```
04/19/69    J BOHAN    THE GE-400 SERIES - FORTRAN ASA (MTPS)            PAGE #    1    J BO  SDL6

C      STRATIFIED FLOW      J P BOHAN
C      PROGRAM TO ANALYZE THE WITHDRAWAL CHARACTERISTICS OF FLOW FROM
C      A RANDOMLY DENSITY STRATIFIED RESERVOIR THRU A SUBMERGED ORIFICE.
C      THREE DIFFERENT CONDITIONS MAY BE SOLVED (1) ORIFICE SIZE AND
C      LOCATION AND WITHDRAWAL LIMITS KNOWN - DETERMINE DISCHARGE
C      (2) ORIFICE SIZE AND LOCATION AND DISCHARGE KNOWN - DETERMINE
C      WITHDRAWAL LIMITS (3) ORIFICE SIZE AND WITHDRAWAL LIMITS KNOWN -
C      DETERMINE ORIFICE ELEVATION AND DISCHARGE
       DIMENSION ELEDEN(20,2),ELETEM(20,3),ELEDOX(20,2),PARAM(300,3),
      1V1(100),V2(100),Q1(100),Q2(100),AVDEN1(100),AVDEN2(100),
      2AVTEM1(100),AVTEM2(100),AVGDO1(100),AVGDO2(100),ICOM(20),IIOM(20)
     5 FORMAT(20A4)
    10 FORMAT(3F5.0,F10.0,F5.0,3F10.0,4I5)
    15 FORMAT(6F10.0)
    20 FORMAT(8F10.0)
    25 FORMAT(1H1,84HSELECTIVE WITHDRAWAL FROM A DENSITY STRATIFIED RESER
      1VOIR THROUGH A SUBMERGED ORIFICE////)
    30 FORMAT(10X,13HRES WIDTH(FT),5X,8HW S ELEV,5X,12HORIF CL ELEV)
    35 FORMAT(12X,F7.1,10X,F6.1,8X,F6.1//)
    40 FORMAT(10X,16HORIF AREA(SQ FT),5X,22HAVG VEL THRU ORIF(FPS),5X,
      114HORIF DISC(CFS))
    45 FORMAT(14X,F7.2,18X,F6.2,16X,F8.2//)
    50 FORMAT(10X,40HELEVATION UPPER LIMIT OF WITHDRAWAL ZONE,3X,F6.1/)
    55 FORMAT(10X,40HELEVATION LOWER LIMIT OF WITHDRAWAL ZONE,3X,F6.1/)
    60 FORMAT(10X,44HELEVATION OF MAX VELOCITY IN WITHDRAWAL ZONE,3X,
      1F6.1/)
    65 FORMAT(10X,37HMAX VELOCITY IN WITHDRAWAL ZONE (FPS),3X,F7.4//)
    70 FORMAT(10X,9HELEVATION,10X,8HVELOCITY/)
    75 FORMAT(10X,F6.1,13X,F7.4)
    80 FORMAT(10X,45HDISCHARGE COMPUTED FROM VELOCITY PROFILE(CFS),3X,
      1F7.2//)
    85 FORMAT(10X,21HDENSITY OF OUTFLOW   ,18HTEMP OF OUTFLOW   ,23HDIS O
      1XY CONT OF OUTFLOW)
    90 FORMAT(10X,F8.6,6H GM/CC,7X,F6.2,6H DEG C,14X,F5.2,5H MG/L)
    95 FORMAT(10X,57HLOWER LIMIT OF WITHDRAWAL ZONE EXTENDS TO BOTTOM BOU
      1NDARY/)
    98.FORMAT(10X,54HUPPER LIMIT OF WITHDRAWAL ZONE EXTENDS TO FREE SURFA
      1CE/)
       READ 5,ICOM
       READ 5,IIOM
       READ 10,G,AO,ZCLO,RW,WS,ZUL,ZLL,Q,KW,NDEN,NTEM,NDOX
       READ 15,((ELETEM(I,J),J=1,3),I=1,NTEM)
       IF(NDEN-0) 100,200,100
   100 READ 20,((ELEDEN(I,J),J=1,2),I=1,NDEN)
   105 II=0
       IF(NDEN-0) 115,110,115
   110 M=ELEDEN(1,1)-ELEDEN(NTEM,1)+1.001
       PARAM(M,1)=ELEDEN(NTEM,2)
       N=NTEM-1
       GO TO 120
   115 M=ELEDEN(1,1)-ELEDEN(NDEN,1)+1.001
       PARAM(M,1)=ELEDEN(NDEN,2)
       N=NDEN-1
   120 DO 190 NN=1,N
```

Fig. C2. Program listing (sheet 1 of 10)

```
          II=II+1                                                  S F  55
          L=NN+1                                                   S F  56
          JXX=ELEDEN(NN,1)-ELEDEN(L,1)                             S F  57
          LL=II+JXX-1                                              S F  58
          IF(ELEDEN(NN,2)-ELEDEN(L,2)) 140,125,160                 S F  59
      125 DO 130 I=II,LL                                           S F  60
          PARAM(I,1)=ELEDEN(NN,2)                                  S F  61
      130 CONTINUE                                                 S F  62
          GO TO 180                                                S F  63
      140 XX=(ELEDEN(L,2)-ELEDEN(NN,2))/JXX                        S F  64
          DO 150 J=II,LL                                           S F  65
          PARAM(J,1)=ELEDEN(NN,2)+XX*(J-II)                        S F  66
      150 CONTINUE                                                 S F  67
          GO TO 180                                                S F  68
      160 YY=(ELEDEN(NN,2)-ELEDEN(L,2))/JXX                        S F  69
          DO 170 K=II,LL                                           S F  70
          PARAM(K,1)=ELEDEN(NN,2)-YY*(K-II)                        S F  71
      170 CONTINUE                                                 S F  72
      180 II=LL                                                    S F  73
      190 CONTINUE                                                 S F  74
          IF(NDEN-0) 200,225,200                                   S F  75
      200 DO 220 KTD=1,NTEM                                        S F  76
          IF(ELETEM(KTD,3)-0) 205,210,205                          S F  77
      205 ELETEM(KTD,2)=(5./9.)*(ELETEM(KTD,3)-32.)                S F  78
      210 IF(NDEN-0) 220,215,220                                   S F  79
      215 ELEDEN(KTD,1)=ELETEM(KTD,1)                              S F  80
          ELEDEN(KTD,2)=1-(((ELETEM(KTD,2)-3.9863)**2/508929.2)*   S F  81
         1((ELETEM(KTD,2)+288.9414)/(ELETEM(KTD,2)+68.12963)))     S F  82
      220 CONTINUE                                                 S F  83
          IF(NDEN-0) 225,105,225                                   S F  84
      225 II=0                                                     S F  85
          N=NTEM-1                                                 S F  86
          DO 295 NN=1,N                                            S F  87
          II=II+1                                                  S F  88
          L=NN+1                                                   S F  89
          JXX=ELETEM(NN,1)-ELETEM(L,1)                             S F  90
          LL=II+JXX-1                                              S F  91
          IF(ELETEM(NN,2)-ELETEM(L,2)) 250,230,270                 S F  92
      230 DO 240 I=II,LL                                           S F  93
          PARAM(I,2)=ELETEM(NN,2)                                  S F  94
      240 CONTINUE                                                 S F  95
          GO TO 290                                                S F  96
      250 XX=(ELETEM(L,2)-ELETEM(NN,2))/JXX                        S F  97
          DO 260 J=II,LL                                           S F  98
          PARAM(J,2)=ELETEM(NN,2)+XX*(J-II)                        S F  99
      260 CONTINUE                                                 S F 100
          GO TO 290                                                S F 101
      270 YY=(ELETEM(NN,2)-ELETEM(L,2))/JXX                        S F 102
          DO 280 K=II,LL                                           S F 103
          PARAM(K,2)=ELETEM(NN,2)-YY*(K-II)                        S F 104
      280 CONTINUE                                                 S F 105
      290 II=LL                                                    S F 106
      295 CONTINUE                                                 S F 107
          M=ELETEM(1,1)-ELETEM(NTEM,1)+1                           S F 108
```

Fig. C2. (sheet 2 of 10)

```
          PARAM(M,2)=ELETEM(NTEM,2)
          READ 20,((ELEDOX(I,J),J=1,2),I=1,NDOX)
          II=0
          N=NDOX-1
          DO 390 NN=1,N
          II=II+1
          L=NN+1
          JXX=ELEDOX(NN,1)-ELEDOX(L,1)
          LL=II+JXX-1
          IF(ELEDOX(NN,2)-ELEDOX(L,2)) 330,310,350
      310 DO 320 I=II,LL
          PARAM(I,3)=ELEDOX(NN,2)
      320 CONTINUE
          GO TO 380
      330 XX=(ELEDOX(L,2)-ELEDOX(NN,2))/JXX
          DO 340 J=II,LL
          PARAM(J,3)=ELEDOX(NN,2)+XX*(J-II)
      340 CONTINUE
          GO TO 380
      350 YY=(ELEDOX(NN,2)-ELEDOX(L,2))/JXX
          DO 360 K=II,LL
          PARAM(K,3)=ELEDOX(NN,2)-YY*(K-II)
      360 CONTINUE
      380 II=LL
      390 CONTINUE
          M=ELEDOX(1,1)-ELEDOX(NDOX,1)+1
          PARAM(M,3)=ELEDOX(NDOX,2)
          PRINT 25
          PRINT 5,ICOM
          PRINT 5,IIOM
          GO TO(400,500,600),KW
      400 N=WS-ZCLO+1.001
          PRINT 30
          PRINT 35,RW,WS,ZCLO
          RHOO=PARAM(N,1)
          N1=WS-ZLL+1.001
          N2=WS-ZUL+1.001
          DRHO1P=PARAM(N1,1)-RHOO
          DRHO2P=RHOO-PARAM(N2,1)
          Z1=ZCLO-ZLL
          Z2=ZUL-ZCLO
          AVZ1=(Z1**2/AO)*SQRT(DRHO1P*G*Z1/RHOO)
          AVZ2=(Z2**2/AO)*SQRT(DRHO2P*G*Z2/RHOO)
          IF(AVZ2-AVZ1) 410,405,435
      405 AV=AVZ1
          Q=AV*AO
          PRINT 40
          PRINT 45,AO,AV,Q
          PRINT 50,ZUL
          PRINT 55,ZLL
          GO TO 498
      410 AV=AVZ2
          Q=AV*AO
          PRINT 40
```

Fig. C2. (sheet 3 of 10)

```
      PRINT 45,AO,AV,Q                                    S F 163
      PRINT 50,ZUL                                        S F 164
      TEST=(AO**2)*RHOO*AV**2/G                           S F 165
      Z1LU=Z1                                             S F 166
      Z1LL=0.0                                            S F 167
      Z1=Z1LU/2                                           S F 168
  415 M=WS-ZCLO+Z1+1.001                                  S F 169
      DRHO1P=PARAM(M,1)-RHOO                              S F 170
      TRY=(Z1**5)*DRHO1P                                  S F 171
      IF(TRY-TEST) 425,420,430                            S F 172
  420 NZLL=ZCLO-Z1+0.5                                    S F 173
      PRINT 55,NZLL                                       S F 174
      GO TO 498                                           S F 175
  425 Z1LL=Z1                                             S F 176
      Z1=(Z1LU+Z1)/2                                      S F 177
      DZ=ABS(Z1LL-Z1)                                     S F 178
      IF(DZ-1) 460,460,415                                S F 179
  430 Z1LU=Z1                                             S F 180
      Z1=(Z1LL+Z1)/2                                      S F 181
      DZ=ABS(Z1LU-Z1)                                     S F 182
      IF(DZ-1) 475,475,415                                S F 183
  435 AV=AVZ1                                             S F 184
      Q=AV*AO                                             S F 185
      PRINT 40                                            S F 186
      PRINT 45,AO,AV,Q                                    S F 187
      PRINT 55,ZLL                                        S F 188
      TEST=(AO**2)*RHOO*AV**2/G                           S F 189
      Z2LL=0.0                                            S F 190
      Z2LU=Z2                                             S F 191
      Z2=Z2LU/2                                           S F 192
  440 M=WS-ZCLO-Z2+1.001                                  S F 193
      DRHO2P=RHOO-PARAM(M,1)                              S F 194
      TRY=(Z2**5)*DRHO2P                                  S F 195
      IF(TRY-TEST) 450,445,455                            S F 196
  445 NZUL=ZCLO+Z2+0.5                                    S F 197
      PRINT 50,NZUL                                       S F 198
      GO TO 498                                           S F 199
  450 Z2LL=Z2                                             S F 200
      Z2=(Z2LU+Z2)/2                                      S F 201
      DZ=ABS(Z2LL-Z2)                                     S F 202
      IF(DZ-1) 480,480,440                                S F 203
  455 Z2LU=Z2                                             S F 204
      Z2=(Z2LL+Z2)/2                                      S F 205
      DZ=ABS(Z2LU-Z2)                                     S F 206
      IF(DZ-1) 495,495,440                                S F 207
  460 Z1=Z1LL                                             S F 208
  465 ZLL=ZCLO-Z1                                         S F 209
      NZLL=ZLL+0.5                                        S F 210
  470 PRINT 55,NZLL                                       S F 211
      GO TO 498                                           S F 212
  475 Z1=Z1LU                                             S F 213
      GO TO 465                                           S F 214
  480 Z2=Z2LL                                             S F 215
  485 ZUL=ZCLO+Z2                                         S F 216
```

Fig. C2. (sheet 4 of 10)

```
      NZUL=ZUL+0.5
  490 PRINT 50,NZUL
      GO TO 498
  495 Z2=Z2LU
      GO TO 485
  498 H=Z1+Z2
      ASSIGN 730 TO JJ
      ASSIGN 780 TO KK
      ASSIGN 830 TO LL
      ASSIGN 880 TO MM
      GO TO 700
  500 PRINT 30
      PRINT 35,RW,WS,ZCLO
      N=WS-ZCLO+1.001
      RHOO=PARAM(N,1)
      AV=Q/AO
      PRINT 40
      PRINT 45,AO,AV,Q
      TEST=(AO**2)*RHOO*AV**2/G
      IF(NDEN-0) 503,502,503
  502 ZB=ZCLO-ELEDEN(NTEM,1)
      DRHOB=ELEDEN(NTEM,2)-RHOO
      GO TO 504
  503 ZB=ZCLO-ELEDEN(NDEN,1)
      DRHOB=ELEDEN(NDEN,2)-RHOO
  504 BTRY=ZB**2/AO
      BTEST=AV/SQRT((DRHOB/RHOO)*G*ZB)
      IF(BTEST-BTRY) 510,510,505
  505 PRINT 95
      Z1=ZB
      NZLL=ZCLO-Z1+0.5
      PRINT 55, NZLL
      ASSIGN 710 TO JJ
      ASSIGN 860 TO MM
      GO TO 545
  510 Z1=ZB/2
      A=0.0
      B=ZB
  515 M=WS-ZCLO+Z1+1.001
      DRHO1P=PARAM(M,1)-RHOO
      TRY=(Z1**5)*DRHO1P
      IF(TRY-TEST)520,540,525
  520 DZ=ABS(B-Z1)
      IF(DZ-0.5)540,522,522
  522 Z1LU=Z1
      Z1LL=B
      Z1=Z1LU+(Z1LL-Z1LU)/2
      A=Z1LU
      GO TO 515
  525 DZ=ABS(A-Z1)
      IF(DZ-0.5)540,527,527
  527 Z1LU=A
      Z1LL=Z1
      Z1=Z1LU+(Z1LL-Z1LU)/2
```

Fig. C2. (sheet 5 of 10)

```
      B=Z1LL
      GO TO 515
  540 NZLL=ZCLO-Z1+0.5
      PRINT 55, NZLL
      ASSIGN 730 TO JJ
      ASSIGN 880 TO MM
  545 ZS=WS-ZCLO
      DRHOS=RHOO-PARAM(1,1)
      STRY=ZS**2/AO
      STEST=AV/SQRT((DRHOS/RHOO)*G*ZS)
      IF(STEST-STRY) 555,555,550
  550 PRINT 98
      Z2=ZS
      NZUL=ZCLO+Z2+0.5
      PRINT 50, NZUL
      H=Z1+Z2
      ASSIGN 760 TO KK
      ASSIGN 810 TO LL
      GO TO 700
  555 Z2=ZS/2
      A=0.0
      B=ZS
  560 M=WS-ZCLO-Z2+1.001
      DRHO2P=RHOO-PARAM(M,1)
      TRY=(Z2**5)*DRHO2P
      IF(TRY-TEST)565,565,570
  565 DZ=ABS(B-Z2)
      IF(DZ-0.5)585,567,567
  567 Z2LL=Z2
      Z2LU=B
      Z2=Z2LL+(Z2LU-Z2LL)/2
      A=Z2LL
      GO TO 560
  570 DZ=ABS(A-Z2)
      IF(DZ-0.5)585,573,573
  573 Z2LL=A
      Z2LU=Z2
      Z2=Z2LL+(Z2LU-Z2LL)/2
      B=Z2LU
      GO TO 560
  585 NZUL=ZCLO+Z2+0.5
      PRINT 50, NZUL
  590 H=Z1+Z2
      ASSIGN 780 TO KK
      ASSIGN 830 TO LL
      GO TO 700
  600 H=ZUL-ZLL
      ASSIGN 730 TO JJ
      ASSIGN 780 TO KK
      ASSIGN 830 TO LL
      ASSIGN 880 TO MM
      ZZU=0.0
      ZZL=0.0
      Z1=H/2
```

Fig. C2. (sheet 6 of 10)

```
      Z2=H-Z1                                              S F 325
      NZCLO=ZLL+Z1+0.5                                     S F 326
      N=WS-NZCLO+1.001                                     S F 327
      N1=WS-ZLL+1.001                                      S F 328
      N2=WS-ZUL+1.001                                      S F 329
      RHOO=PARAM(N,1)                                      S F 330
      DRHO1P=PARAM(N1,1)-RHOO                              S F 331
      DRHO2P=RHOO-PARAM(N2,1)                              S F 332
      LM=3                                                 S F 333
  610 AVZ1=(Z1**2/AO)*SQRT(DRHO1P*G*Z1/RHOO)               S F 334
      AVZ2=(Z2**2/AO)*SQRT(DRHO2P*G*Z2/RHOO)               S F 335
      DAVZ=ABS(AVZ2-AVZ1)                                  S F 336
      IF(DAVZ-0.005) 690,690,620                           S F 337
  620 GO TO(630,640,650),LM                                S F 338
  630 IF(AVZ2-AVZ1) 675,690,670                            S F 339
  640 IF(AVZ2-AVZ1) 655,690,660                            S F 340
  650 IF(AVZ2-AVZ1) 655,690,670                            S F 341
  655 ZZU=Z1                                               S F 342
      GO TO 665                                            S F 343
  660 ZZL=Z1                                               S F 344
  665 ZZ=(ZZU-ZZL)/2                                       S F 345
      Z1=ZZ+ZZL                                            S F 346
      Z2=H-Z1                                              S F 347
      NZCLO=ZLL+Z1+0.5                                     S F 348
      N=WS-ZCLO+1.001                                      S F 349
      RHOO=PARAM(N,1)                                      S F 350
      DRHO1P=PARAM(N1,1)-RHOO                              S F 351
      DRHO2P=RHOO-PARAM(N2,1)                              S F 352
      LM=2                                                 S F 353
      GO TO 610                                            S F 354
  670 ZZL=Z2                                               S F 355
      GO TO 680                                            S F 356
  675 ZZU=Z2                                               S F 357
  680 ZZ=(ZZL-ZZU)/2                                       S F 358
      Z2=ZZ+ZZU                                            S F 359
      Z1=H-Z2                                              S F 360
      NZCLO=ZLL+Z1+0.5                                     S F 361
      N=WS-NZCLO+1.001                                     S F 362
      RHOO=PARAM(N,1)                                      S F 363
      DRHO1P=PARAM(N1,1)-RHOO                              S F 364
      DRHO2P=RHOO-PARAM(N2,1)                              S F 365
      LM=1                                                 S F 366
      GO TO 610                                            S F 367
  690 ZCLO=NZCLO                                           S F 368
      PRINT 30                                             S F 369
      PRINT 35,RW,WS,ZCLO                                  S F 370
      AV=AVZ1                                              S F 371
      Q=AV*AO                                              S F 372
      PRINT 40                                             S F 373
      PRINT 45,AO,AV,Q                                     S F 374
      PRINT 55,ZLL                                         S F 375
      PRINT 50,ZUL                                         S F 376
  700 Z1H=Z1/H                                             S F 377
      Y1MH=(SIN(1.5708*Z1H))**2                            S F 378
```

Fig. C2. (sheet 7 of 10)

```
          Y1M=Y1MH+H                                  S F 379
          NY1M=Y1M+0.5                                S F 380
          Y1M=NY1M                                    S F 381
          ZMV=ZCLO-Z1+Y1M                             S F 382
          NZMV=ZMV+0.5                                S F 383
          ZMV=NZMV                                    S F 384
          NH=H+0.5                                    S F 385
          H=NH                                        S F 386
          PRINT 60,ZMV                                S F 387
          Y2M=H-Y1M                                   S F 388
          M=WS-ZMV+1.001                              S F 389
          RHOVM=PARAM(M,1)                            S F 390
          M=WS-ZMV-Y2M+1.001                          S F 391
          DRHO2M=RHOVM-PARAM(M,1)                     S F 392
          M=WS-ZMV+Y1M+1.001                          S F 393
          DRHO1M=PARAM(M,1)-RHOVM                     S F 394
          YD1M=Y1M*DRHO1M                             S F 395
          YD2M=Y2M*DRHO2M                             S F 396
          SUM1=0.0                                    S F 397
          L=Y1M                                       S F 398
          GO TO JJ,(710,730)                          S F 399
      710 DO 720 I=0,L                                S F 400
          Y1=I                                        S F 401
          M=WS-ZMV+Y1+1.001                           S F 402
          DRHO1=PARAM(M,1)-RHOVM                      S F 403
          VRA1=1-(Y1*DRHO1/YD1M)**2                   S F 404
          SUM1=SUM1+VRA1                              S F 405
      720 CONTINUE                                    S F 406
          GO TO 750                                   S F 407
      730 DO 740 I=0,L                                S F 408
          Y1=I                                        S F 409
          M=WS-ZMV+Y1+1.001                           S F 410
          DRHO1=PARAM(M,1)-RHOVM                      S F 411
          VRA1=(1-Y1*DRHO1/YD1M)**2                   S F 412
          SUM1=SUM1+VRA1                              S F 413
      740 CONTINUE                                    S F 414
      750 SUM2=0.0                                    S F 415
          K=Y2M                                       S F 416
          GO TO KK,(760,780)                          S F 417
      760 DO 770 J=1,K                                S F 418
          Y2=J                                        S F 419
          M=WS-ZMV-Y2+1.001                           S F 420
          DRHO2=RHOVM-PARAM(M,1)                      S F 421
          VRA2=1-(Y2*DRHO2/YD2M)**2                   S F 422
          SUM2=SUM2+VRA2                              S F 423
      770 CONTINUE                                    S F 424
          GO TO 800                                   S F 425
      780 DO 790 J=1,K                                S F 426
          Y2=J                                        S F 427
          M=WS-ZMV-Y2+1.001                           S F 428
          DRHO2=RHOVM-PARAM(M,1)                      S F 429
          VRA2=(1-Y2*DRHO2/YD2M)**2                   S F 430
          SUM2=SUM2+VRA2                              S F 431
      790 CONTINUE                                    S F 432
```

Fig. C2. (sheet 8 of 10)

```
  800 SUM=SUM1+SUM2                                    S F 433
      VM=Q/(RW*SUM)                                    S F 434
      PRINT 65,VM                                      S F 435
      PRINT 70                                         S F 436
      LIMIT1=Y2M-1+0.001                               S F 437
      GO TO LL,(810,830)                               S F 438
  810 DO 820 L=0,LIMIT1                                S F 439
      Y2=Y2M-L                                         S F 440
      M=WS-ZMV-Y2+1.001                                S F 441
      DRHO2=RHOVM-PARAM(M,1)                           S F 442
      V2(L+1)=(1-(Y2*DRHO2/YD2M)**2)*VM                S F 443
      ELEV2=ZMV+Y2                                     S F 444
      PRINT 75,ELEV2,V2(L+1)                           S F 445
  820 CONTINUE                                         S F 446
      GO TO 850                                        S F 447
  830 DO 840 L=0,LIMIT1                                S F 448
      Y2=Y2M-L                                         S F 449
      M=WS-ZMV-Y2+1.001                                S F 450
      DRHO2=RHOVM-PARAM(M,1)                           S F 451
      V2(L+1)=((1-Y2*DRHO2/YD2M)**2)*VM                S F 452
      ELEV2=ZMV+Y2                                     S F 453
      PRINT 75,ELEV2,V2(L+1)                           S F 454
  840 CONTINUE                                         S F 455
  850 N=Y1M                                            S F 456
      GO TO MM,(860,880)                               S F 457
  860 DO 870 K=1,N                                     S F 458
      Y1=K                                             S F 459
      M=WS-ZMV+Y1+1.001                                S F 460
      DRHO1=PARAM(M,1)-RHOVM                           S F 461
      V1(K)=(1-(Y1*DRHO1/YD1M)**2)*VM                  S F 462
      ELEV1=ZMV-Y1                                     S F 463
      PRINT 75,ELEV1,V1(K)                             S F 464
  870 CONTINUE                                         S F 465
      GO TO 900                                        S F 466
  880 DO 890 K=1,N                                     S F 467
      Y1=K                                             S F 468
      M=WS-ZMV+Y1+1.001                                S F 469
      DRHO1=PARAM(M,1)-RHOVM                           S F 470
      V1(K)=((1-Y1*DRHO1/YD1M)**2)*VM                  S F 471
      ELEV1=ZMV-Y1                                     S F 472
      PRINT 75,ELEV1,V1(K)                             S F 473
  890 CONTINUE                                         S F 474
  900 L=Y2M                                            S F 475
      SUM3=((VM+V2(L))/2)*RW                           S F 476
      LIMIT2=Y2M-2+0.001                               S F 477
      DO 910 J=0,LIMIT2                                S F 478
      M=WS-ZMV-Y2M+J+1.001                             S F 479
      N=M+1                                            S F 480
      VAVG2=(V2(J+1)+V2(J+2))/2                        S F 481
      Q2(J+1)=VAVG2*RW                                 S F 482
      SUM3=SUM3+Q2(J+1)                                S F 483
      AVDEN2(J+1)=(PARAM(N,1)+PARAM(M,1))/2            S F 484
      AVTEM2(J+1)=(PARAM(N,2)+PARAM(M,2))/2            S F 485
      AVGDO2(J+1)=(PARAM(N,3)+PARAM(M,3))/2            S F 486
```

Fig. C2. (sheet 9 of 10)

```
  910 CONTINUE
      SUM4=((VM+V1(1))/2)*RW
      LIMIT3=Y1M-1+0.001
      DO 920 I=1,LIMIT3
      M=WS-ZMV+I+1.001
      L=M-1
      VAVG1=(V1(I)+V1(I+1))/2
      Q1(I)=VAVG1*RW
      SUM4=SUM4+Q1(I)
      AVDEN1(I)=(PARAM(L,1)+PARAM(M,1))/2
      AVTEM1(I)=(PARAM(L,2)+PARAM(M,2))/2
      AVGDO1(I)=(PARAM(L,3)+PARAM(M,3))/2
  920 CONTINUE
      SUMQ=SUM3+SUM4
      PRINT 80,SUMQ
      SDEN2=0.0
      STEM2=0.0
      SDOX2=0.0
      LIMIT4=Y2M-1+0.001
      DO 930 I=1,LIMIT4
      PCENQ2=Q2(I)/SUMQ
      DEN2=PCENQ2*AVDEN2(I)
      SDEN2=SDEN2+DEN2
      TEMP2=PCENQ2*AVTEM2(I)
      STEM2=STEM2+TEMP2
      DISOX2=PCENQ2*AVGDO2(I)
      SDOX2=SDOX2+DISOX2
  930 CONTINUE
      L=WS-ZMV+1.001
      M=Y2M+0.001
      N=WS-ZMV+0.001
      SDEN2=SDEN2+((((VM+V2(M))/2)*RW)/SUMQ)*((PARAM(L,1)+PARAM(N,1))/2)
      STEM2=STEM2+((((VM+V2(M))/2)*RW)/SUMQ)*((PARAM(L,2)+PARAM(N,2))/2)
      SDOX2=SDOX2+((((VM+V2(M))/2)*RW)/SUMQ)*((PARAM(L,3)+PARAM(N,3))/2)
      N=WS-ZMV+2.001
      SDEN1=((((VM+V1(1))/2)*RW)/SUMQ)*((PARAM(L,1)+PARAM(N,1))/2)
      STEM1=((((VM+V1(1))/2)*RW)/SUMQ)*((PARAM(L,2)+PARAM(N,2))/2)
      SDOX1=((((VM+V1(1))/2)*RW)/SUMQ)*((PARAM(L,3)+PARAM(N,3))/2)
      LIMIT5=Y1M-1+0.001
      DO 940 J=1,LIMIT5
      PCENQ1=Q1(J)/SUMQ
      DEN1=PCENQ1*AVDEN1(J)
      SDEN1=SDEN1+DEN1
      TEMP1=PCENQ1*AVTEM1(J)
      STEM1=STEM1+TEMP1
      DISOX1=PCENQ1*AVGDO1(J)
      SDOX1=SDOX1+DISOX1
  940 CONTINUE
      DEN=SDEN1+SDEN2
      TEMP=STEM1+STEM2
      DISOXY=SDOX1+SDOX2
      PRINT 85
      PRINT 90,DEN,TEMP,DISOXY
      STOP77777
      END
```

Fig. C2. (sheet 10 of 10)

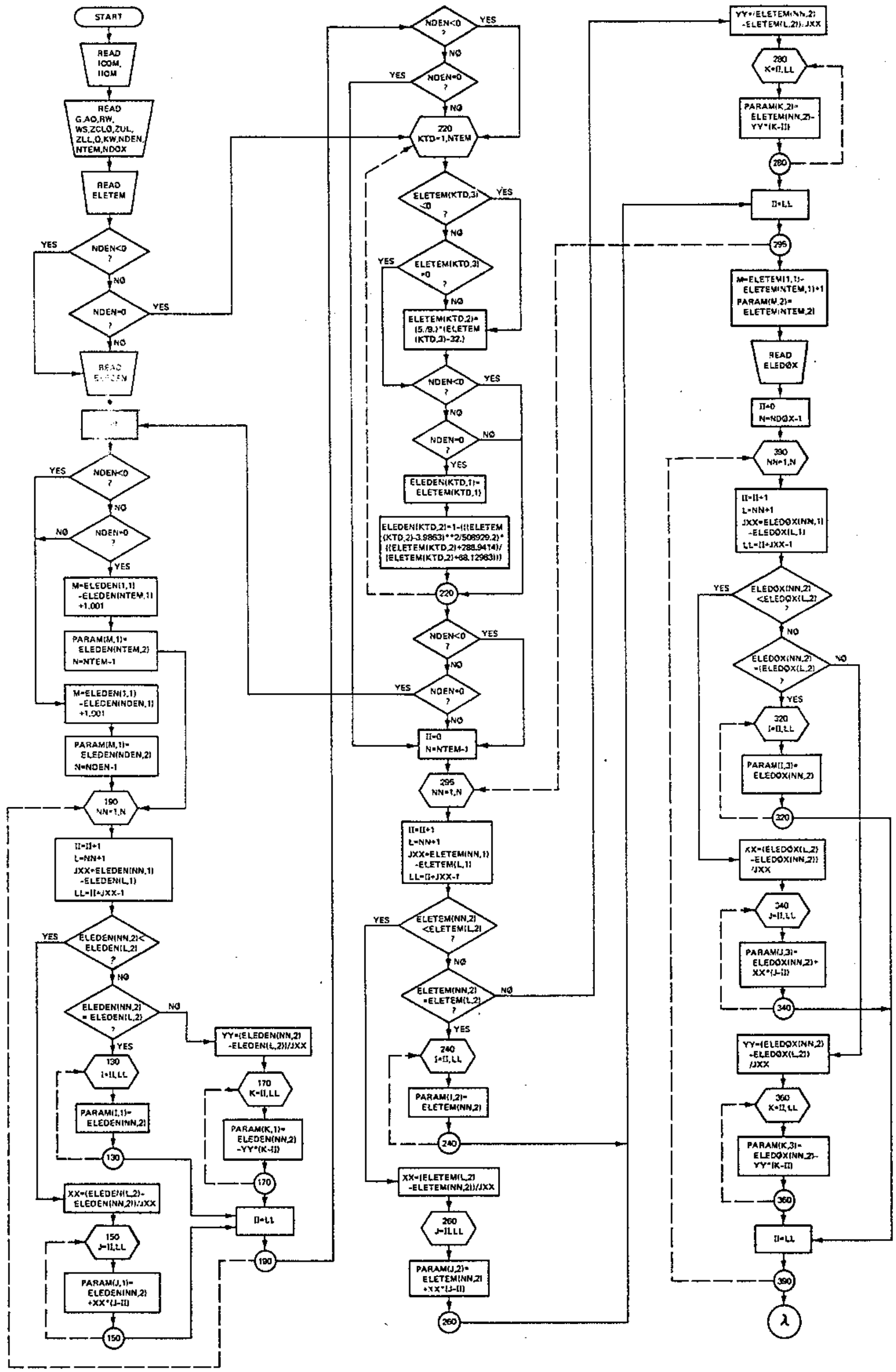

Fig. C3. Flow chart (sheet 1 of 5)

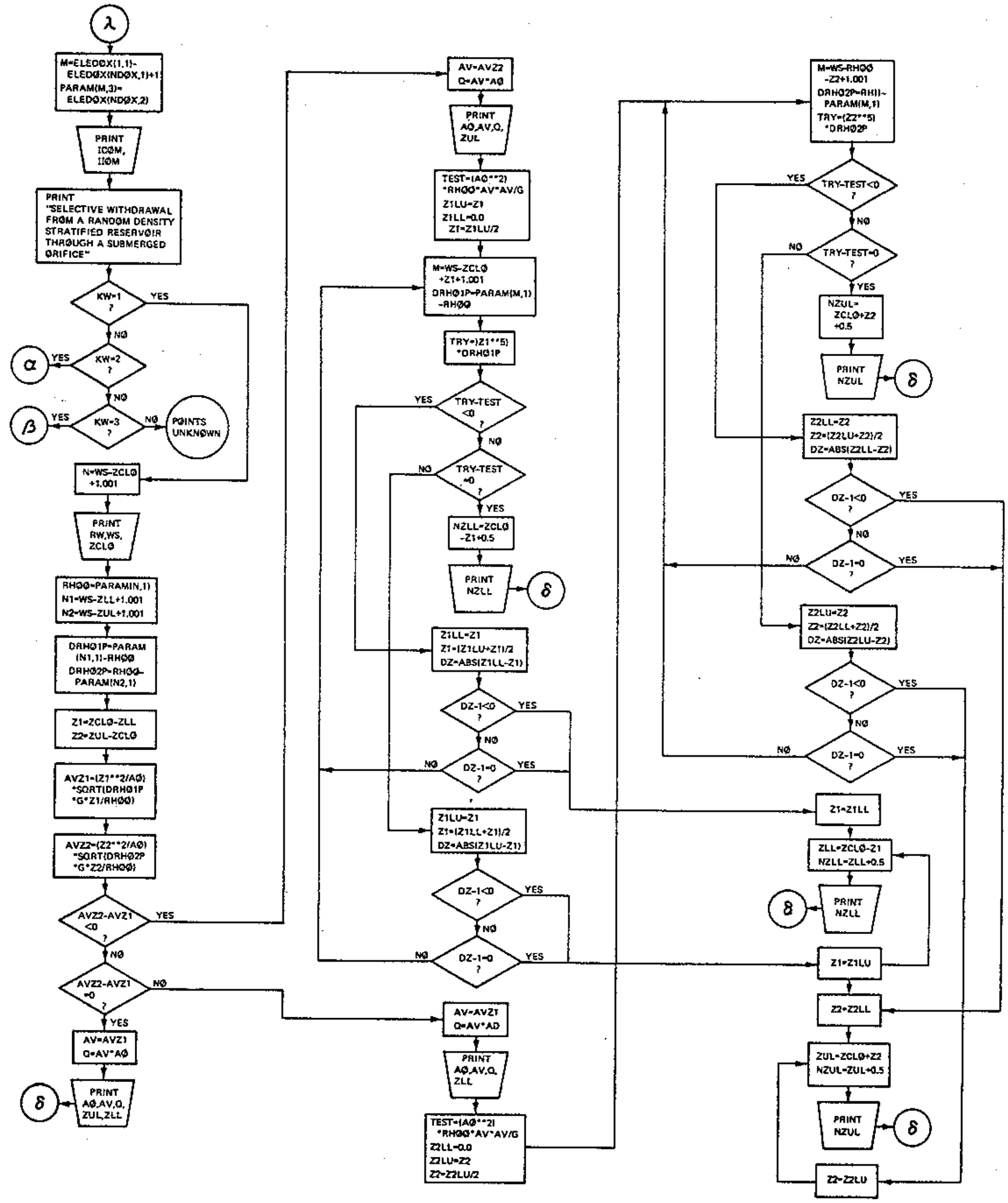

Fig. C3. Flow chart (sheet 2 of 5)

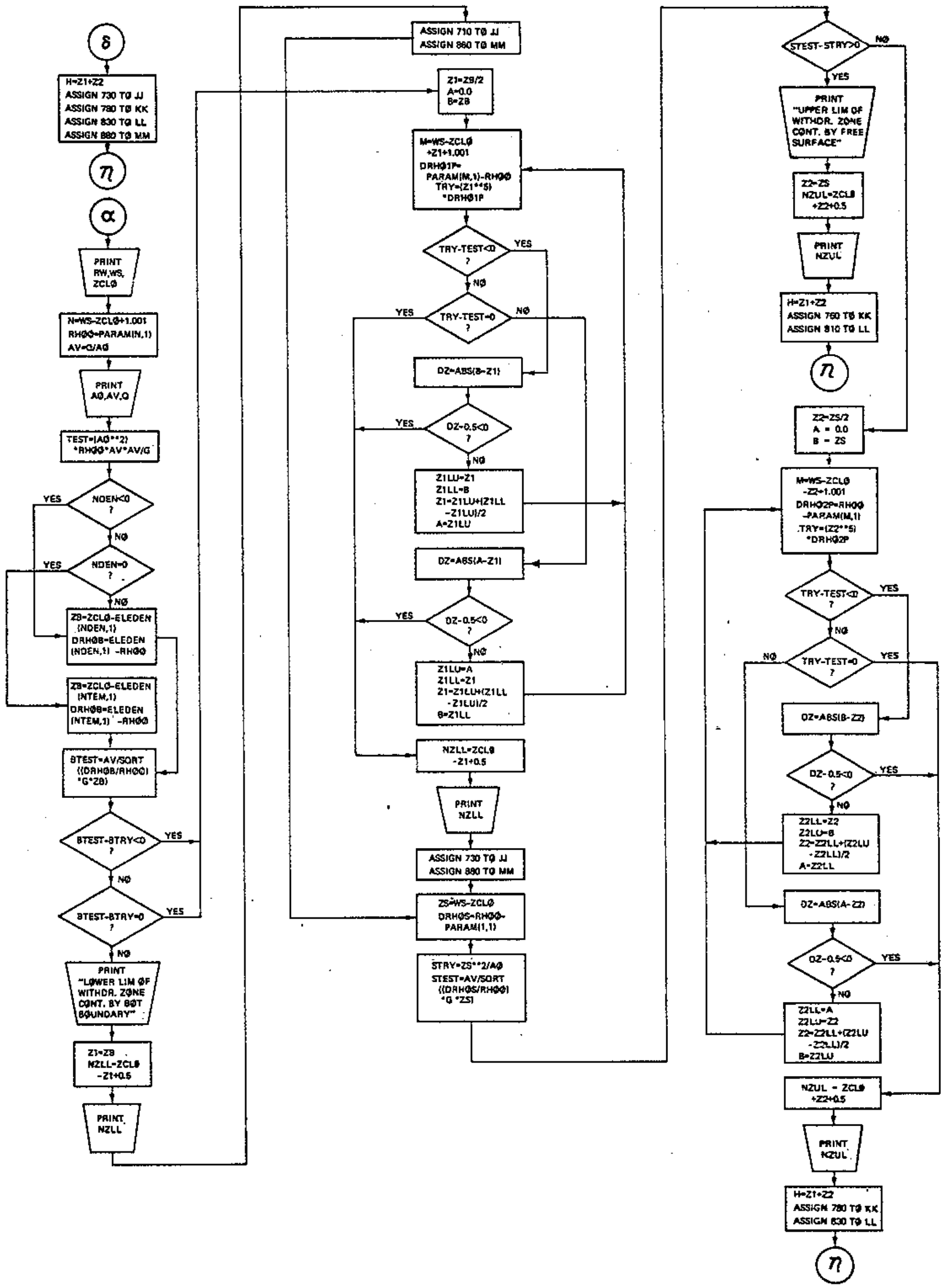

Fig. C3. Flow chart (sheet 3 of 5)

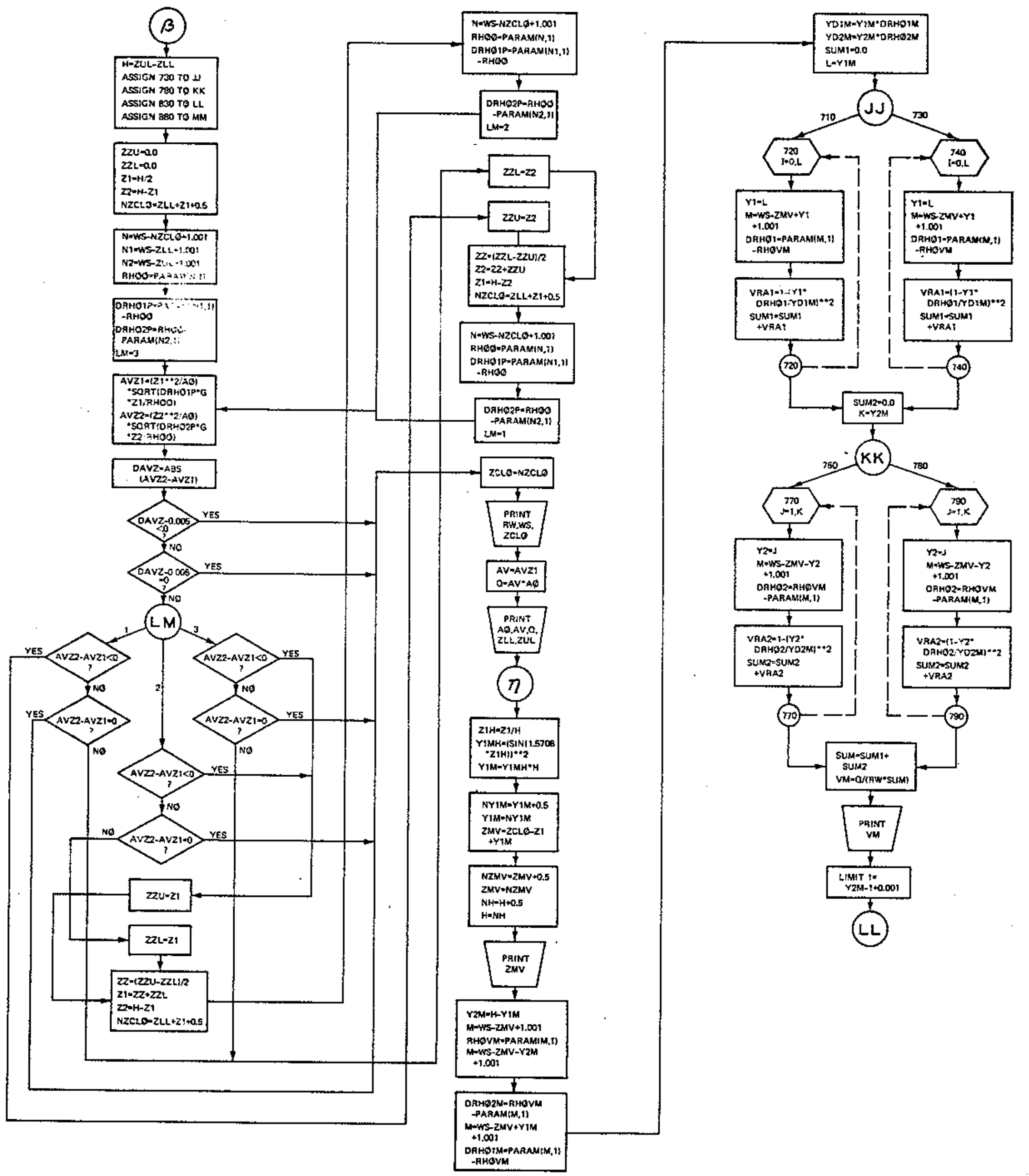

Fig. C3. Flow chart (sheet 4 of 5)

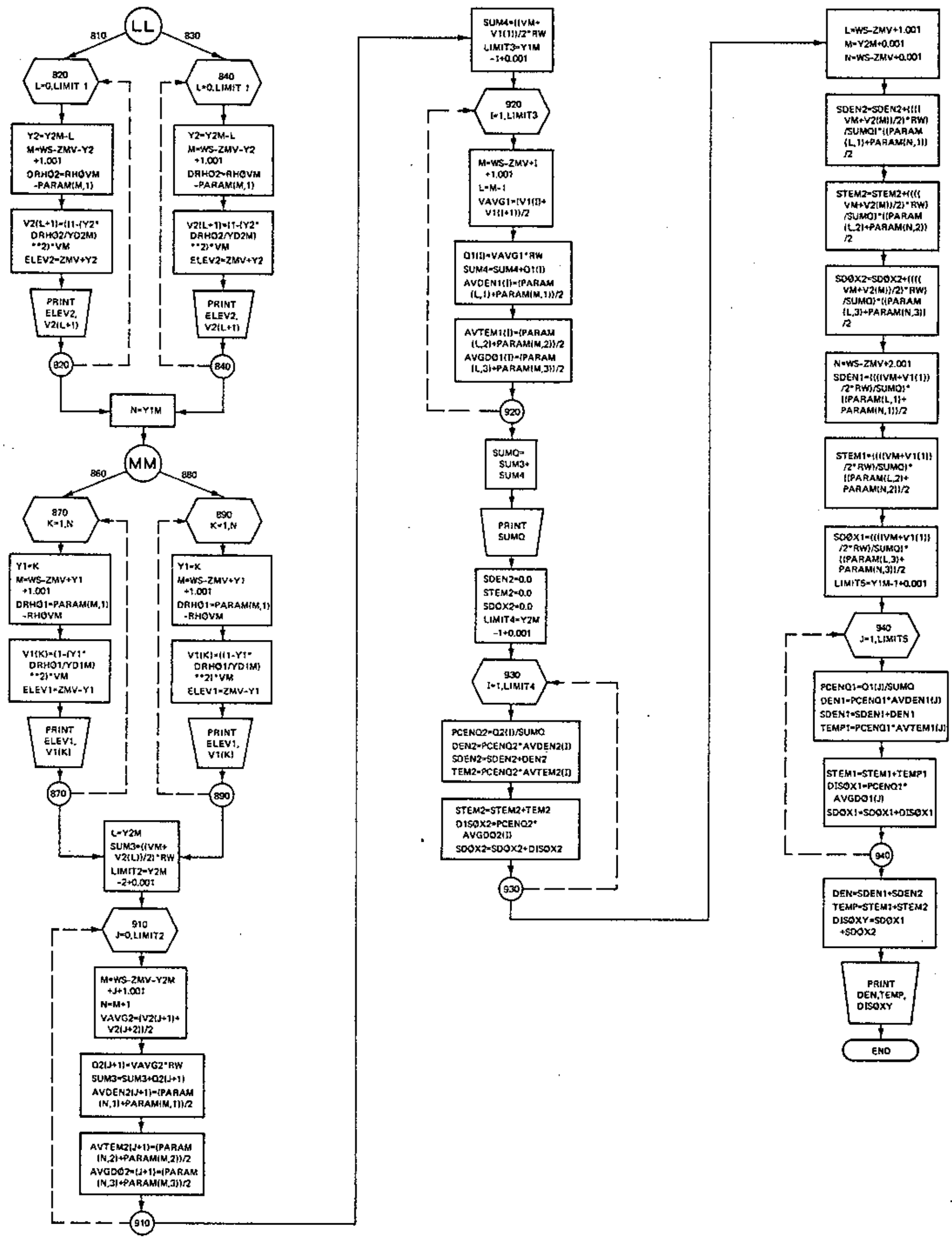

Fig. C3. Flow chart (sheet 5 of 5)

GENERAL PURPOSE DATA FORM

PROGRAM: STRATIFIED FLOW 2 (22-G2-R0-098)
REQUESTED BY: J. P. BOHAN
PREPARED BY: J. P. BOHAN
CHECKED BY: A. CHECK
DATE: 14 APRIL 1969
PAGE: 1 OF 1

SAMPLE PRØBLEM - THE ØRIF SIZE AND LØCATIØN ARE FIXED AND THE DESIRED DISCHARGE
IS GIVEN. THE WITHDRAWAL LIMITS ARE TØ BE CØMPUTED. THEREFØRE USE CØNDITIØN (2)

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
32.2 64.	190.	1000. 200.	0.	0.	400.	2 0	10. 5
200.	0.	78.	190.	0.	77.		
180.	0.	76.	175.	0.	74.		
170.	0.	68.	165.	0.	62.		
160.	0.	58.	150.	0.	57.		
100.	0.	54.	0.	0.	46.		
200.	6.8	170.	5.6	150.	4.8	60.	3.9
0.	1.1						

WES FORM NO. 1233
SEPTEMBER 1962

Fig. C4. Example of program input

SELECTIVE WITHDRAWAL FROM A DENSITY STRATIFIED RESERVOIR THROUGH A SUBMERGED ORIFICE

SAMPLE PROBLEM - THE ORIF SIZE AND LOCATION ARE FIXED AND THE DESIRED DISCHARGE IS GIVEN. THE WITHDRAWAL LIMITS ARE TO BE COMPUTED. THEREFORE USE CONDITION 2

RES WIDTH(FT)	W S ELEV	ORIF CL ELEV
1000.0	200.0	190.0

ORIF AREA(SQ FT)	AVG VEL THRU ORIF(FPS)	ORIF DISC(CFS)
64.00	6.25	400.00

ELEVATION LOWER LIMIT OF WITHDRAWAL ZONE 168.0

UPPER LIMIT OF WITHDRAWAL ZONE EXTENDS TO FREE SURFACE

ELEVATION UPPER LIMIT OF WITHDRAWAL ZONE 200.0

ELEVATION OF MAX VELOCITY IN WITHDRAWAL ZONE 193.0

MAX VELOCITY IN WITHDRAWAL ZONE (FPS) 0.0172

ELEVATION	VELOCITY
200.0	0.0000
199.0	0.0079
198.0	0.0127
197.0	0.0154
196.0	0.0166
195.0	0.0171
194.0	0.0172
192.0	0.0172
191.0	0.0172
190.0	0.0171
189.0	0.0170
188.0	0.0169
187.0	0.0167
186.0	0.0166
185.0	0.0164
184.0	0.0161
183.0	0.0159
182.0	0.0156
181.0	0.0153
180.0	0.0150
179.0	0.0142
178.0	0.0133
177.0	0.0123
176.0	0.0113
175.0	0.0103
174.0	0.0080
173.0	0.0059
172.0	0.0039
171.0	0.0023
170.0	0.0010
169.0	0.0003
168.0	0.0000

DISCHARGE COMPUTED FROM VELOCITY PROFILE(CFS) 400.00

DENSITY OF OUTFLOW	TEMP OF OUTFLOW	DIS OXY CONT OF OUTFLOW
0.997145 GM/CC	24.71 DEG C	6.29 MG/L

Fig. C5. Example of program output

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1. ORIGINATING ACTIVITY (Corporate author)
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Miss.

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
MECHANICS OF FLOW FROM STRATIFIED RESERVOIRS IN THE INTEREST OF WATER QUALITY; Hydraulic Laboratory Investigation

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report

5. AUTHOR(S) (First name, middle initial, last name)
Joseph P. Bohan
John L. Grace, Jr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1969	84	23

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
Technical Report H-69-10

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT
Investigations were conducted to determine the characteristics of the withdrawal zone resulting from the release of flow through an orifice from a randomly stratified reservoir in experimental facilities for the purpose of developing means of predicting the quality of water discharged through similar openings in prototype intake structures. Distributions of density, generated by differentials in both temperature and dissolved salt concentration, and velocity were observed at various locations within a 1-ft-wide channel upstream of 0.08- and 0.16-ft-square orifices. These data were used to develop generalized expressions describing the limits of the zone of withdrawal and the distribution of velocities therein. In certain cases, the proximity of the free surface and/or bottom boundary may dictate the upper and/or lower limits of the zone of withdrawal. Means were developed (Appendix A) for evaluating the conditions under which these boundaries dictate the limits of the withdrawal zone and for determining the distribution of velocities within a zone of withdrawal restricted by boundary conditions. A sample problem (Appendix B) is presented to illustrate application of the results to determine the maximum discharge that may be released through a square orifice for a given set of conditions without exceeding the limits of a desired hypothetical zone of withdrawal. The example also illustrates how the actual limits of the zone of withdrawal and the velocity distribution therein are determined. A method is illustrated for predicting the dissolved oxygen content and/or other water quality parameters of the outflow provided the vertical distributions of these parameters in the reservoir are known. A FORTRAN IV program is presented in Appendix C. This program can be used to solve three different approaches to the selective withdrawal problem: (1) determination of the allowable discharge for selected withdrawal limits and orifice

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size and elevation; (2) determination of the withdrawal zone characteristics for a selected discharge and orifice size and elevation; and (3) determination of the allowable discharge and orifice elevation for selected withdrawal limits and orifice size. The density and/or temperature profile in the reservoir must be known or assumed for all three conditions. The effect of orifice shape on the withdrawal characteristics was tested and analyzed after the draft of this report was prepared. The results were believed to be pertinent and are discussed briefly in the Discussion section of this report.

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