B-147-63, Computation of Outflow from Breached Dams, June 1963

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COMPUTATION OF OUTFLOW FROM BREACHED DAMS
JUNE 1963

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COMPUTATION OF OUTFLOW FROM BREACHED DAMS

DECEMBER 1962
PREFACE

This guide on Computation of Outflow From Breached Dams contains intelligence which is not readily available through other media required for the accomplishment of the assigned mission of the Production Center and of interest to other agencies. Comments on this guide are solicited from all recipients. Comments should be addressed to:

Department of Defense
Defense Intelligence Agency (DIAAP-1E)
Washington 25, D.C.
ABSTRACT

The failure or demolition of high dams, impounding large volumes of water, may release large flood waves capable of seriously damaging downstream military and civilian installations and of disrupting river crossings and other military operations. The outflow from a breached dam is influenced by the dimensions of the breach, the volume and shape of the reservoir, tailwater conditions, reservoir inflow, and other variables. The theoretical and experimental equations used to compute the breach outflow in civilian practice are very complex and too time-consuming for military use. Simplified step-by-step procedures for determining the flow through the breach are developed in this study to permit fairly rapid prediction of the breach outflow hydrograph with a degree of accuracy acceptable for military situations. Computation procedures with illustrative examples are given for three types of breach: 1) a small breach with the size and shape of the breach and the total reservoir storage governing the outflow; 2) a medium breach with a steep negative wave in the reservoir significantly affecting outflow; and 3) a large breach with tailwater submergence, as well as the factors previously listed, affecting outflow.
# COMPUTATION OF OUTFLOW FROM BREACHED DAMS

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CHAPTER 1

INTRODUCTION

1. Purpose

The purpose of this Engineer Intelligence Guide (EIG) is to provide military engineers with step-by-step procedures for computing fairly rapid estimates, of suitable accuracy for military purposes, of the rates of outflow to be expected from breached dams.

2. Scope

This guide presents methods of computing approximate rates of outflow suitable for use in various combinations of breach, reservoir, and tailwater conditions. The approximations used in the guide conform as closely as possible to basic hydraulic principles, are intended to expedite the computations, and utilize types of data likely to be available in military situations. These approximations involve 1) adjustment of basic data to "idealize" the breach and the reservoir, 2) determination of peak outflows from breaches of various types, 3) reservoir-routing procedures, and 4) determination of the effect of tailwater submergence. The EIG outlines the theoretical basis for the methods used and includes a detailed exposition of the computational procedure techniques with illustrative examples.

3. References

Useful references are listed at the end of the text.

4. Discussion of problem

a. Military significance. High dams impounding large volumes of water are located on many rivers throughout the world. The failure or demolition of such dams could create major flood waves capable of producing disastrous damage to downstream military and civilian installations, bridges, and industrial plants, disrupting navigation and irrigation, and causing loss of life. River-crossing operations in the combat zone could be delayed or prevented. Frequently, the presence of a dam in the headwaters under the control of the opposing force would necessitate the assembly and construction of river-crossing equipment capable of withstanding a major flood wave, thereby acting as a deterrent to the operation.

b. Hydraulic considerations. The destructiveness of an artificial flood wave is directly related to the peak discharge through the breached dam, and this discharge is largely determined by the size and position of the breach. With the advent of atomic weapons, any size of breach can now be created in a dam ranging from complete destruction of the dam to the removal of a spillway gate. The hydraulic principles
governing the determination of the rate of outflow from a breached dam involve complex theories and assumptions too time-consuming for military use. The size and position of a breach opening also influence the nature of the outflow. A need therefore exists for a method of determining the rate of flow through a breach of any given size which is sufficiently accurate for military purposes, but which employs reasonable approximations and computational short-cuts in the derivation.

c. Relation to previous studies. A number of theoretical studies and experiments have been performed to develop methods of computing the dam-breach flood wave which are suitable for military use. Military Hydrology Bulletins 9 and 10 (References 7 and 8) presented, in the form of a manual, the methods of computing outflow hydrographs from breached dams according to standard discharge formulas and reservoir-routing techniques. These bulletins employed certain simplifying assumptions concerning the water-surface profile in the reservoir during the period immediately following breaching and gave little consideration to the effect of tailwater submergence on outflow. More recent studies (References 11-13) have developed clearer concepts of the reservoir water-surface profile during the passage of a steep negative wave after breaching and of the effect of tailwater submergence. These concepts provide a suitable basis for a reasonably accurate mathematical procedure of determining the outflow hydrograph, taking into account the effects of the negative wave and submergence. This EIG is intended to combine the results of all these studies, and, to as great an extent as possible without a significant loss of accuracy, simplify and expedite the method of computation of the outflow hydrograph.

d. Additional studies needed. This guide contains no information on the characteristics of breaches created by explosives, and does not present a method of determining the artificial flood hydrograph at points downstream from a breached dam. Laboratory and field investigations of such dam breaches are greatly needed, especially in the case of earth dams. Short-cut methods of routing the breach outflow hydrograph to downstream points will be developed in a future study.

5. Abbreviations and nomenclature

a. The following abbreviations are used in this study:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>cfs</td>
<td>cubic feet per second</td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
</tr>
<tr>
<td>ft²</td>
<td>square feet</td>
</tr>
<tr>
<td>ft³</td>
<td>cubic feet</td>
</tr>
<tr>
<td>hr</td>
<td>hour(s)</td>
</tr>
<tr>
<td>km</td>
<td>kilometer(s)</td>
</tr>
<tr>
<td>m</td>
<td>meters</td>
</tr>
<tr>
<td>m²</td>
<td>square meters</td>
</tr>
<tr>
<td>m³</td>
<td>cubic meters</td>
</tr>
<tr>
<td>m³/sec</td>
<td>cubic meters per second</td>
</tr>
<tr>
<td>msl</td>
<td>mean sea level</td>
</tr>
<tr>
<td>sec</td>
<td>second(s)</td>
</tr>
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</table>

b. The symbols used in the formulas and graphs are explained in Table 1. Definition sketches of the physical and hydraulic dimensions of breach and reservoir are presented on Plate 1.

c. Conversion factors for English and metric units are given in Table 2.
6. Analysis of elements involved

a. **Scope.** The computation of the outflow hydrograph from a breached dam involves the determination of a series of component elements covering a wide range of hydraulic principles. This EIG explains these basic principles only in as much detail as is necessary to understand the computational methods used in this EIG.

b. **Basic data to be evaluated.** The following variables generally must be evaluated before the breach outflow hydrograph can be computed:

1. The dimensions and position of the breach.
2. The dimensions of reservoir cross sections at the dam and at various distances upstream.
3. The volume of water stored in the reservoir at the time of breaching and at lower reservoir levels.
4. The rate of inflow into the reservoir.
5. The variable relation between breach discharge rates and water-surface elevations just below the dam.

c. **Idealization of breach and reservoir.** After these basic data have been determined, the size and shape of both the breach and reservoir must be "idealized." Idealization greatly simplifies the mathematical relationships between breach discharge, reservoir stage, storage, and time of wave travel. It also eliminates the need for detailed measurements of the reservoir and breach. Thus, idealization conforms to the usual military situation in which time and facilities for computation, as well as necessary detailed data, are limited. The idealized breach (Plate 1) is rectangular in cross section with a depth below the reservoir surface equal to that of the actual breach. Its width is computed in such a way that the peak discharge through the idealized breach is the same as that through the actual breach. Its shape can be considered to approximate an actual breach sufficiently closely for most military purposes. The idealized reservoir is a pyramid with rectangular cross sections. It has the same length and storage capacity as the actual reservoir at the initial pool elevation; its width is determined from these values. This shape provides a reasonable approximation of the shape of most reservoirs and permits simplification of formulas without outstanding significant error.

d. **Peak discharge.** The next determination is the peak discharge through the breach. This important value is also needed to fix the
character of the breach (small, medium, large) and the method to be used in deriving the outflow hydrograph. Accordingly, three successive approximations of the peak discharge are computed, as follows:

(1) The first approximation takes into account only the discharge capacity of the breach itself but not the effect of the distortion of the water surface produced by a steep negative wave traveling upstream through the reservoir, nor the effect of tailwater submergence. If these effects are not significant, the breach is designated a small breach.

(2) The second approximation takes into account the discharge capacity of the breach and the negative wave effect but not the effect of tailwater submergence. If the negative wave effect is significant but that of tailwater submergence is not, the breach is designated a medium breach.

(3) The third approximation takes into account all three factors: breach capacity, negative wave, and tailwater submergence effects. If the effect of tailwater submergence is significant, the breach is designated a large breach.

e. Breach outflow hydrograph. The final procedure is the determination of the breach outflow hydrograph. The method of computation to be used in a specific case is determined by the character of the breach as discussed above.

f. Factors not considered. Other factors which have an effect on breach outflow, such as the gradual enlargement of the breach over a period of time, reservoir bed resistance, and wave reflection, are not considered in this EIG. They are difficult to evaluate and are not necessary, since the accuracy gained by using them is less than the margin of error in the basic data and formulas used.

7. Basic data assumed to be known

a. Before it is possible to compute the breach outflow hydrograph, certain basic data corresponding to those listed in paragraph 6b must be determined and expressed in a form suitable for use in the computations. These data and the ways in which they are usually obtained are described in the following subparagraphs.

b. Breach dimensions and position. It is assumed that the following characteristics of the actual breach are known:

(1) The breach cross section or its shape and dimensions.

(2) The initial depth of the reservoir above the bottom of the breach.

(3) The elevation of the bottom of the breach above the bottom of the reservoir at the dam.
These data are used to determine the width of the actual breach at the initial reservoir elevation and the area of the actual breach below that elevation. (The determination of the actual dimensions of a breach created by explosives is beyond the scope of this guide.)

c. Reservoir dimensions. The dimensions of the cross section of the reservoir at the dam and the length of the reservoir at the initial pool elevation can be determined from design reports, topographic maps, or aerial photographs. The cross section of the reservoir at the dam is used to obtain the depth of the lowest point in the streambed (ignoring minor discontinuities or holes of short width) below the initial reservoir water surface.

d. Reservoir storage.

(1) The total volume of water stored in the reservoir at the initial pool elevation is most readily obtained from the reservoir storage curve usually available in design reports.

(2) If this curve is lacking, reservoir storage may be determined from a topographic map of the reservoir site by measuring the areas within contours of elevation with a planimeter, multiplying each area by the increment of elevation, and adding these volumes.

(3) If both storage curve and topographic maps are lacking but other maps or aerial photographs are available for determining the surface area of the reservoir at a known elevation, total storage at the initial pool elevation may be estimated by the following method:

(a) Select a value of $c$ for the appropriate type of reservoir terrain from the following tabulation:

<table>
<thead>
<tr>
<th>Type of reservoir</th>
<th>Value of c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake</td>
<td>1.0 to 1.5</td>
</tr>
<tr>
<td>Flood plain and foothill</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td>Hill</td>
<td>2.5 to 3.5</td>
</tr>
<tr>
<td>Gorge</td>
<td>3.5 to 4.5</td>
</tr>
</tbody>
</table>

(b) Compute $a = A/cH^c-1$, where $A$ is the surface area of the reservoir at a given elevation and $H$ is the depth of the reservoir at the dam at the same elevation.

(c) Compute $S_0 = a(H_0)^c$, where $S_0$ is the total storage at the initial reservoir elevation and $H_0$ is the initial depth of the reservoir at the dam.

e. Reservoir inflow rate. It is assumed that the rate of inflow to the reservoir is constant during the period of breach outflow. The rate may be determined or estimated from the dam operation records for similar periods or from records of upstream and downstream gaging stations.
and dams. The effect of reservoir inflow is significant only when it constitutes a considerable proportion of the total outflow, for example, after an upstream dam has been breached or during flood periods.

f. Tailwater rating curve. The tailwater discharge rating curve expresses the relationship between rate of discharge at a point just below the dam and the elevation of the stream surface at that point above the bottom of the reservoir at the dam. This curve is usually found in dam design reports. The curve may also be computed or extended by any standard method, such as Manning's formula (References 3 or 9). This formula is usually stated (for metric and English units respectively) as

$$Q = \frac{AR^{2/3}S^{0.5}}{n}$$

and

$$Q = 1.49AR^{2/3}S^{0.5}/n,$$

where $Q$ is the discharge, $A$ the area of the stream cross section, $R$ the hydraulic radius, $S$ the slope of the water surface, and $n$ the channel roughness coefficient. (This terminology is from standard hydraulics texts and does not correspond to Table 1, Symbols.)

g. System of measurement. All data must be expressed in the same units of measurement. The system to be used, English or metric, must be decided in advance to arrive at the final solution of the outflow hydrograph in the desired units.

8. Idealization of breach

The idealized breach is of rectangular cross section, and its bottom is at the same elevation as the bottom of the actual breach (Plate 1). In order to compute the width of the idealized breach, the initial or peak discharge of the actual breach is set equal to that of the idealized breach. The average initial depth $h_m$ in the actual breach is computed by the equation

$$h_m = \frac{A_{max}}{B_{max}}$$

where $A_{max}$ is the area of the breach below the initial reservoir water surface and $B_{max}$ is the width of the breach at the initial reservoir water surface elevation. The critical-depth formula for flow over a broad-crested rectangular weir, which is considered a reasonable approximation of flow conditions in the actual breach, is used to compute the peak discharge $Q_{max}$. This formula is given by the equation:

$$Q_{max} = 0.545g^{0.5}(h_m)^{3/2}B_{max}$$

where $Q_{max}$ is the peak discharge and $g$ is the acceleration of gravity. The value $Q_{max}$ may be obtained from the nomograph for this equation, Plate 2a or b. Then, using the same nomograph and the same value of $Q_{max}$, the value of $B$ satisfying the equation $Q_{max} = 0.545g^{0.5}(h_0)^{3/2}B$ is determined, with $h_0$ the initial depth over the bottom of the breach, and $B$ the width of the idealized rectangular breach. The detailed method of computing idealized breach dimensions is shown in steps 2-4, paragraph 14b.
9. Idealization of reservoir

The idealized reservoir has the same initial storage volume, length, and initial depth at the dam as the actual reservoir. The shape of the idealized reservoir at the time of breaching is that of a pyramid with rectangular cross sections. The width of the idealized reservoir at the dam is computed by the equation

\[ B_0 = \frac{3S_0}{LH_o} \]

as derived from the basic formula for the volume of a rectangular pyramid. \( B_0 \) is the width of the idealized reservoir at the dam, \( S_0 \) the initial storage volume, \( L \) the initial length, and \( H_o \) the initial depth of the reservoir at the dam. This computation corresponds to step 5, paragraph 14c.

10. Successive approximations of the peak discharge

a. The first approximation of the peak discharge, \( Q_{\text{max}} \), is obtained by using Equation 2 (paragraph 8). The detailed method is given in steps 2 and 3, paragraph 14d.

b. The second approximation of the peak discharge, \( Q_0 \), is obtained by a procedure developed in References 11 and 12. This procedure takes into account the effect of a steep negative wave created by the breaching of the dam. The negative wave (Plate 1) causes a sudden lowering of the reservoir surface at the dam and therefore a peak discharge \( Q_0 \) less than \( Q_{\text{max}} \), the first approximation. The detailed method of computing \( Q_0 \) is given in steps 6-12, paragraph 14d. It involves the use of curves and equations to determine the relative height of the negative wave and the peak discharge \( Q_0 \). The basic principle involved is that at the time of the peak the discharge through the breach is equal to the natural reservoir inflow plus a discharge represented by the product of the area and celerity of the negative wave at a section near the breach. In other words, the height of the negative wave is in hydraulic balance with the depth of flow through the breach.

c. The third approximation of the peak discharge, \( Q_{\text{th}} \), is obtained by modifying the procedure for the second approximation if there is significant tailwater submergence. Tailwater submergence (Plate 1) occurs when water levels below the dam are higher than the bottom of the breach.

(1) To determine whether there is any tailwater submergence, determine from the tailwater discharge rating curve whether the second approximation of the peak discharge \( Q_0 \) corresponds to a downstream water-surface elevation above the bottom of the breach. Since the value of the second approximation must exceed that of third (the effect
of submergence being to decrease rate of flow), this procedure is an adequate test for the absence of submergence.

(2) If the preceding test indicates possible submergence, it must then be determined whether the submergence will have a significant effect on breach outflow. Villemonte's formula (Reference 4, page 218) is applied:

\[
\beta = \left[ 1 - \left( \frac{h_d}{k} \right)^{1.5} \right]^{0.385}
\]

where \( \beta \) is the submergence ratio, \( h_d \) the tailwater elevation above the bottom of the breach, and \( k \) the energy head on the breach as shown on the definition sketch, Plate 1. This formula, although strictly applicable to sharp-crested weirs, was chosen for this guide because convenient and because it is believed that no serious error will result from its use. When \( h_d/k = 0.4 \), \( \beta = 0.9 \), so that for this value of \( h_d/k \) the discharge as affected by submergence is 90% of the free discharge, a value considered within the range of accuracy of the basic data and formulas. Accordingly, the value \( h_d/k \) corresponding to \( Q_0 \), the second approximation of the peak discharge, is determined. If it is equal to or less than 0.4, submergence effect is not considered significant and the third approximation is not needed. These tests correspond to steps 13 and 14, paragraph 14e.

(3) If the ratio \( h_d/k \) is greater than 0.4, the third approximation of the peak discharge \( Q'_0 \) is computed by the following trial-and-error method:

(a) A series of breach discharge rating curves for various submergence ratios is computed by the equation for flow at critical depth through a rectangular weir.

\[
Q = 0.545 g \frac{0.5}{\beta} \frac{k}{B}^{3/2}
\]

where \( Q \) is the discharge, \( g \) the acceleration of gravity, \( B \) the width of the breach, \( k \) the energy head, and \( \beta \) the submergence ratio.

(b) A relation between \( Q_a \), the approach discharge in the reservoir, and \( k \), the energy head, is developed by assigning trial values to the height of the negative wave and computing corresponding values of \( Q_a \) and \( k \).

(c) A graphical method is used to determine the value of the submergence ratio which satisfies Equation 4 at the point of intersection of the \( Q_a \) curve with the \( Q \) curve computed by using that ratio. The point of intersection is \( Q'_0 \), the third approximation of the peak discharge. The detailed procedure for determining \( Q'_0 \) is given in steps 15-18, paragraph 14e.

11. Determination of the breach outflow hydrograph

a. Selection of breach type. The method to be used in determining the breach outflow hydrograph is governed by the type of breach involved, and this in turn is based on the values of successive approximations of the peak discharge. Accordingly, the following steps (corresponding to steps 19-21, paragraph 14f) are used to determine the type of breach and the method of procedure:
(1) If $Q_0$, the second approximation of the peak discharge, is equal to or greater than 90% of $Q_{\text{max}}$, the first approximation, and if the tests for submergence show that the computation of the third approximation $Q'_0$ is unnecessary, follow the procedure for small breaches as described below.

(2) If $Q'_0$, the third approximation of the peak discharge, is equal to or greater than 90% of $Q_0$, the second approximation (or if the tests for submergence show that the computation of $Q'_0$ is unnecessary), and if $Q_0$ is less than 90% $Q_{\text{max}}$, follow the procedure for medium breaches described below.

(3) If $Q'_0$ is less than 90% $Q_0$, follow the procedure for large breaches described below.

b. Small breach procedure. The procedure for the computation of the outflow hydrograph from a small breach is based on a mathematical analysis of the inflow-outflow-storage relation. In a small breach the reservoir water surface is not significantly distorted by the passage of a steep negative wave, and the breach discharge is not significantly affected by submergence. Therefore there is a single-valued relation between reservoir water-surface elevation at the dam and reservoir storage, and between reservoir water-surface elevation at the dam and breach discharge. Hence a single-valued relation exists between reservoir storage and breach discharge. In those instances when the reservoir inflow is small enough to be neglected, an integrable differential equation may be derived relating storage, discharge and time, by combining the reservoir storage equation, as expressed in the exponential form $S = aH^c$, with the equation for breach discharge. When inflow to the reservoir is appreciable, the resulting differential equation is integrable only for certain values of the storage exponent $c$, and the breach discharge hydrograph must usually be obtained by interpolation. Values of the storage exponent $c$ for a rectangular pyramidal reservoir, as a function of the ratio of the depth below the bottom of the breach to the total reservoir depth at the dam, are shown on Plate 9. Breach outflow hydrographs for the combination of small rectangular breach and rectangular reservoir are shown in dimensionless form for integrable values of the storage exponent $c$: as functions of the peak discharge $Q_{\text{max}}$ and the total reservoir storage above the bottom of the breach on Plate 10 for the condition of small reservoir inflow, and on Plate 11 for the condition of appreciable inflow. The detailed method of computing the outflow hydrograph from a small breach is given in steps 22-30, paragraph 14g.

c. Medium breach procedure. The procedure for the computation of the outflow hydrograph from a medium breach, as developed in References 11 and 12, is based on the assumption that the height of the negative wave created by the breach and used in computing the second approximation of the peak discharge $Q_0$ remains constant as the wave progresses upstream. As the wave progresses, its celerity and cross-sectional area decrease
as the depth and width of the reservoir decrease. Formulas are derived in References 11 and 12 based on assumptions that simplify the complex factors involved in these phenomena; the formulas are for computing the time of arrival of the negative wave at a given point in the reservoir, and the celerity and cross-sectional area of the negative wave at that point. These formulas, which are expressed in dimensionless parametric form, are used to compute the time and discharge coordinates of a fictitious inflow hydrograph which represents the time of arrival and rate of discharge of the negative wave at various points in the reservoir. After the fictitious inflow hydrograph has been computed, it is numerically routed through the reservoir by the standard level-pool reservoir routing method to obtain the breach outflow hydrograph. The reservoir storage involved in this routing is that between the bottom of the negative wave and the bottom of the breach, since the storage above the bottom of the negative wave has been distributed into the fictitious inflow hydrograph. These two storage values may be used for approximately checking the breach outflow hydrograph. The detailed method of computing the outflow hydrograph from a medium breach is given in steps 31-40, paragraph 14h.

d. Large breach procedure. In this EIG it is assumed that if the breach discharge is large enough to create tailwater submergence, a steep negative wave must also have been created in the reservoir. Hence the procedure for determining the outflow hydrograph from a large breach is a modification of the procedure for a medium breach incorporating a method of determining the effect of tailwater submergence on breach outflow. A detailed analysis of this procedure is given in Reference 13. The effect of tailwater submergence is introduced into the procedure by computing the average breach discharge rating curve for submergence conditions by a trial-and-error method using Equation 4 to compute the submergence factor. The remaining steps in the determination of the outflow hydrograph from a large breach (including the computation of the fictitious inflow hydrograph and reservoir routing) essentially duplicate those for a medium breach. The detailed method of computing the outflow hydrograph for a medium breach is given in steps 41-52, paragraph 14i.
CHAPTER 3

DETAILED PROCEDURES FOR THE DETERMINATION OF THE OUTFLOW HYDROGRAPH

12. General

This chapter presents the detailed steps to be followed in the determination of the outflow hydrograph from a breached dam, together with the required basic data assumed to be known; Plate 14 outlines these steps graphically. The symbols used are defined in Table 1, and definition sketches of breach and reservoir dimensions and hydraulic characteristics are presented on Plate 1. Four examples are given in the next chapter that illustrate the application of these procedures. A highly-simplified method of estimating the outflow hydrograph for a large breach is presented in Appendix A.

13. Data assumed to be known

Item

1. \( h_0 \) Depth of reservoir above bottom of breach at time of breaching
2. Cross section of breach
3. \( H_0 \) Depth of reservoir at dam at time of breaching
4. \( S_0 \) Total reservoir storage at time of breaching
5. \( L \) Length of reservoir at time of breaching
6. Cross section of reservoir at dam
7. \( p_0 \) Constant rate of inflow into reservoir
8. Tailwater discharge rating curve
9. System of measurement (English or metric) to be used in determination

14. Steps in the determination of the outflow hydrograph

a. Conversion of units of measurement

Step

1. If necessary, convert items 1-8 of the data assumed to be known to the units of measurement to be used in the determination of the hydrograph (item 9 of known data).

b. Idealization of breach

2. On the breach cross section (item 2, known data) measure \( B_{\text{max}} \), the
width of the breach at elevation $h_0$ (item 1, known data). Compute $A_{max}$; the area of the breach below elevation $h_0$. Divide $A_{max}$ by $B_{max}$ to obtain $h_m$, the average depth of water in the breach at the time of breaching.

3. Enter nomograph on Plate 2a or b (corresponding to the system of measurement used) with the values of $h_m$ and $B_{max}$ obtained in step 2, to determine $Q_{max}$, the first approximation of the peak discharge.

4. Enter the nomograph used in step 3 with the values of $Q_{max}$ (step 3) and $h_0$ (item 1 of known data) to obtain $B$, the width of the idealized breach.

c. **Idealization of reservoir**

5. Using items 3, 4, and 5 of known data, compute $B_0$, the width of the idealized reservoir at the dam, by the formula $B_0 = 3S_0/LH_0$.

d. **Second approximation of the peak discharge**

6. Enter the nomograph on Plate 3a or b (corresponding to the system of measurement used) with the values of $B_0$ (step 5) and $H_0$ (item 3 of known data) to obtain $B_0H_0(gH_0)^{0.5}$. 

7. Compute $w = \frac{P_0}{B_0H_0(gH_0)^{0.5}}$ rounding off $w$ to the nearest 0.05 value. $P_0$: item 7 of known data; $B_0H_0(gH_0)^{0.5}$: step 6). Note: If $P_0 = 0$, $w = 0$.

8. Compute $s = \frac{h_0}{H_0}$ ($h_0$, $H_0$: items 1 and 3 of known data).

9. Compute $m = 0.545B/B_0$ ($B$, $B_0$: steps 4 and 5).

10. Determine from Plates 4a thru k the value $p$ corresponding to $w$, $s$, and $m$ (steps 7-9).

11. Determine from Plate 5 the value $f(p,w) = p(1 - p/2)^{0.5} - w$ corresponding to $p$ and $w$ (steps 10 and 7).

12. Compute $Q_0 = P_0 + B_0H_0(gH_0)^{0.5}f(p,w)$ ($P_0$: item 7 of known data; $B_0H_0(gH_0)^{0.5}$, $f(p,w)$: steps 6 and 11). $Q_0$ is the second approximation of the peak discharge.

e. **Third approximation of the peak discharge**

13. (a) If necessary, extend the tailwater discharge rating curve (item 8 of known data) to pass through $Q_0$ (step 12).

(b) From this curve determine the elevation $H_d$ corresponding to $Q_0$. ($H_d$ is the tailwater water-surface elevation above the bottom of the reservoir at the dam.)

(c) Compute $H_c = H_0 - h_0$ ($H_0$, $h_0$: items 3 and 1 of known data). ($H_c$
is the elevation of the bottom of the breach above the bottom of the reservoir at the dam.)

(d) Compare $H_d$ with $H_c$. If $H_d$ is greater than $H_c$, compute $h_d = H_d - H_c$. If $H_d$ is equal to or less than $H_c$, omit steps 14 thru 18, the remaining steps for the computation of the third approximation.

14 (a) Enter the nomograph on Plate 2a or b (corresponding to the system of measurement used) with the values of $Q_0$ (step 12) and $B$ (step 4) to obtain $k$, the energy head above the bottom of the breach corresponding to $Q_0$.

(b) Compute $0.4k$.

(c) Compare $h_d$ (step 13(d)) with $0.4k$. If $h_d$ is equal to or less than $0.4k$, omit steps 15 thru 18, the remaining steps for the computation of the third approximation.

15 Determine the breach discharge rating curve with no submergence effect as follows:

(a) Select a series of values of discharge $Q$ ranging from $P_0$ (item 7 of known data) to approximately $120\% Q_0$ (step 12).

(b) For each value of $Q$ selected enter the nomograph on Plate 2a or b (corresponding to the system of measurement used) to obtain the value of $k$ corresponding to $Q$ and $B$ (step 4).

(c) On graph paper plot corresponding values of $Q$ and $k$, and draw a smooth curve through the plotted points. This is the breach discharge rating curve with no submergence effect. Label the curve $\beta = 1.00$, $\beta$ representing the submergence ratio.

16 Determine the relation between breach discharge and velocity head as follows:

(a) Tabulate the series of values of discharge $Q$ used in step 15 up to $Q_0$, and the corresponding values of $k$.

(b) Compute $Q/B_0$ ($B_0$: step 5).

(c) Determine from Plate 6 the value $D$ corresponding to $Q/B_0$.

(d) Compute $k + H_c$ ($H_c$: step 13(c)).

(e) Determine the value $H$ satisfying the equation $k + H_c = H + D/H^2$, by the trial-and-error method illustrated in Example 2.

(f) Compute $\Delta k = k + H_c - H = D/H^2$. ($\Delta k$ is the velocity head.)
(g) Plot corresponding values of $Q$ and $\Delta k$ on graph paper and draw a smooth curve through the plotted points. This is the relation between breach discharge and velocity head.

17 Determine the rating curve for discharge of approach as follows:

(a) Select a series of values of $p'$ ranging approximately from $p$ (step 10) to $p/2$.

(b) For each value of $p'$ determine from Plate 5 the value $f(p',w) = p' \left(1 - p'/2\right)^{0.5} - \bar{w}$ (w: step 7).

(c) For each value of $p'$ compute $Q_a = P_0 + B_0 H_0 (gH_0)^{0.5} f(p',w)$ (P_0: item 7 of known data; $B_0 H_0 (gH_0)^{0.5}$: step 6).

(d) For each value of $p'$ compute $h' = p'H_0$ and $h_o - h'$ ($H_0$ and $h_o$: items 3 and 1 of known data).

(e) Determine $\Delta k$ for each value of $Q_a$ from the curve showing the relation between $Q$ and $\Delta k$ (step 16(g)).

(f) For each value of $Q_a$ compute $k = h_o - h' + \Delta k$.

(g) Plot corresponding values of $Q_a$ and $k$ on the same graph as the breach discharge rating curve (step 15(c)) and draw a smooth curve through the plotted points. This is the rating curve for discharge of approach $Q_a$.

18 Determine the peak discharge with submergence as follows:

(a) Assign a range of trial values to the submergence ratio $\beta_1$.

(b) Multiply several values of discharge on the breach rating curve for $\beta = 1.00$ (step 15(c)) by each trial value $\beta_1$.

(c) For each trial value $\beta_1$ construct a curve on the same graph paper as that for $\beta = 1.00$ by plotting these products against the values of $k$ corresponding to the discharges on the $\beta = 1.00$ curve. Label each curve so obtained with the value of $\beta_1$.

(d) Determine the values of $Q_a$ and $k$ at the point of intersection of each curve with the $Q_a$ curve (step 17).

(e) On the tailwater discharge rating curve (step 13) determine the elevation $H_d$ corresponding to the value of $Q_a$ at each point of intersection, and compute $h_d = H_d - H_c$ ($H_c$: step 13c).

(f) Compute the value $h_d/k$ corresponding to $Q_a$ at each point of intersection.
(g) Determine the submergence ratio $\beta_2$ corresponding to each value of $h_d/k$ on Plate 7.

(h) On graph paper plot corresponding values of $Q_a$ and $\beta_1$ at each point of intersection, and draw a smooth curve through the plotted points. Also plot corresponding values of $Q_a$ and $\beta_2$, and draw another curve through these points. Determine the values of $Q_a$ and $\beta$ at the point of intersection of these two curves.

(i) Repeat steps (b) through (g) using the value of $\beta$ obtained in (h) as $\beta_1$. The value $\beta_2$ thereby derived should approximately equal $\beta_1$. If not, the process should be repeated. The value $Q_a$ derived in this step is the third approximation of the peak discharge $Q_0^i$.

f. Selection of breach type

19 If the third approximation of the peak discharge was not computed (steps 13 and 14), compare the values of $Q_o$ (step 12) and $Q_{max}$ (step 3). If $Q_o$ is equal to or greater than 90% $Q_{max}$, use the small-breach procedure for determining the outflow hydrograph, steps 22-30.

20 (a) If the third approximation of the peak discharge was not computed (steps 13 and 14), and $Q_o$ is less than 90% $Q_{max}$, use the medium-breach procedure for determining the outflow hydrograph, steps 31-40.

(b) If the third approximation was computed, compare the values of $Q_o$ (step 18(i)) and $Q_o$. If $Q_o$ is equal to or greater than 90% $Q_o$, use the medium-breach procedure, steps 31-40.

21 If the third approximation of the peak discharge was computed, and $Q_o$ is less than 90% $Q_o$, use the large-breach procedure for determining the outflow hydrograph, steps 41-52.

g. Small-breach procedure

22 Compute the effective reservoir storage $S_e$ above the bottom of the breach as follows:

(a) Compute $H_c/H_o$ ($H_c$: step 13(c); $H_o$: item 3 of known data).

(b) Determine from Plate 8 the storage factor $R$ corresponding to $H_c/H_o$.

(c) Compute $S_e = S_o(1 - R)$ ($S_o$: Item 4 of known data).
23 Determine from Plate 9 the storage exponent \( c \) corresponding to \( H_C/H_O \) (step 22(a)).

24 Compute \( t_k = S_e/Q_{max} \) (\( S_e \): step 22(c); \( Q_{max} \): step 3).

25 Compare \( P_0 \) (item 7 of known data) with \( Q_{max} \) (step 3). If \( P_0 \) is less than 10% \( Q_{max} \), follow the procedure given in steps 26-27, which applies to small breaches with small reservoir inflow. If \( P_0 \) is equal to or greater than 10% \( Q_{max} \), follow the procedure given in steps 28-30 which applies to small breaches with appreciable reservoir inflow.

26 Compute the breach outflow hydrograph with small reservoir inflow as follows:
   
   (a) Enter Plate 10 with the value of \( c \) determined in step 23 and tabulate the value of \( t/t_k \) corresponding to each of a series of values of \( Q/Q_{max} \).
   
   (b) Multiply each value of \( t/t_k \) by \( t_k \) (step 24) and each value of \( Q/Q_{max} \) by \( Q_{max} \) (step 3) to obtain \( t \) and \( Q \), respectively.
   
   (c) Add \( P_0 \) (item 7 of known data) to each value of \( Q \) to obtain \( Q_t \), the total discharge at time \( t \) after breaching.
   
   (d) On graph paper plot corresponding values of \( Q_t \) and \( t \), and draw a smooth curve through the plotted points. This is the breach outflow hydrograph for a small breach with small reservoir inflow.

27 To check approximately the preceding computations, proceed as follows:
   
   (a) Compute the volume of the breach outflow hydrograph (step 26(d)).
   
   (b) To the effective reservoir storage \( S_e \) (step 22(c)) add \( P_0 t \), where \( t \) is the duration of the breach outflow hydrograph. The results of (a) and (b) should be approximately equal.

28 When reservoir inflow is appreciable, compute \( P_0/Q_{max} \) (\( P_0 \): item 7 of known data; \( Q_{max} \): step 3).

29 Determine the breach outflow hydrograph with appreciable reservoir inflow as follows:
   
   (a) Enter Plate 11 with the values of \( P_0/Q_{max} \) and \( c \) (step 23) and by interpolation tabulate values of \( t/t_k \) corresponding to a series of values of \( Q/Q_{max} \).
   
   (b) Multiply each value of \( Q/Q_{max} \) by \( Q_{max} \) (step 3) and each value of \( t/t_k \) by \( t_k \) (step 24) to obtain \( Q \) and \( t \), respectively.
(c) On graph paper plot corresponding values of Q and t, and draw a smooth curve through the plotted points. This is the outflow hydrograph for a small breach with appreciable reservoir inflow.

30 To check approximately the preceding computations, proceed as follows:

(a) Compute the volume of the breach outflow hydrograph (step 29(c)).

(b) To the effective reservoir storage $S_e$ (step 22(c)) add $P_0 t$, where $t$ is the duration of the breach outflow hydrograph. The results of (a) and (b) should be approximately equal.

h. Medium-breach procedure

31 Determine the fictitious inflow hydrograph as follows:

(a) Enter Plate 12 with the values of $p$ (step 10) and $w$ (step 7) to obtain for each of a series of values of $x$ ranging from 1 to $p/2$ the corresponding value of $f(x,p,w) = x(x - p/2)^{0.5} - w/x$.

(b) For each value of $x$ compute $P_w = pB_0H_0(gH_0)^{0.5}f(x,p,w)$ ($B_0H_0(gH_0)^{0.5}$: step 6).

(c) For each value of $x$ compute $P_n = P_0 + P_w$ ($P_0$: item 7 of known data).

(d) Enter Plate 13 with the same values of $x$, $p$, and $w$ used in (a) to obtain corresponding values of $F(x,p,w) = t(gH_0)^{0.5}/L$.

(e) Compute $L/(gH_0)^{0.5}$, obtaining $(gH_0)^{0.5}$ from Plate 3a or b (corresponding to the system of measurement used) ($L$, $H_0$: items 5 and 3 of known data).

(f) Multiply each value of $F(x,p,w)$ by $L/(gH_0)^{0.5}$ to obtain $t$. Also compute the time $t$ at which $P_n = P_0$ by the formula $t = 2L/[(gH_0)^{0.5}(1 - w)]$.

(g) Plot on graph paper values of $P_n$ and $t$ corresponding to the same values of $x$, and draw a smooth curve through the plotted points. This is the fictitious inflow hydrograph.

32 Determine the relation between breach discharge and reservoir water-surface elevation as follows: Select a series of values of discharge $Q$ ranging from $P_0$ (item 7 of known data) to $Q_0$ (step 12). For each value of $Q$:

(a) Compute $Q/B_0$ ($B_0$: step 5).

(b) Determine from Plate 6 the value $D$ corresponding to $Q/B_0$. 


(c) Enter the nomograph on Plate 2a or Plate 2b (corresponding to the system of measurement used) with the values of Q and B to obtain the value of k, the energy head above the bottom of the breach. (B: step 4).

(d) Compute \( k + \frac{H}{c} \) (\( H_c \): step 13(c)).

(e) By the trial-and-error method illustrated in Example 1 determine the value \( H \) satisfying the equation \( k + \frac{H}{c} = H + \frac{D}{H^2} \). (\( H \) is the reservoir water-surface elevation above the bottom of the reservoir at the dam corresponding to the discharge Q.)

(f) Plot corresponding values of \( H \) and \( Q \) on graph paper, and draw a smooth curve through the plotted points. This is the relation between breach discharge and reservoir water-surface elevation.

By inspection of the fictitious inflow hydrograph (step 33(g)) determine the time interval \( \Delta t \) for which values of \( P_\text{in} \) adequately define the hydrograph. (Ordinarily, in order to expedite later computations, two values of \( \Delta t \) are used: one for the upper portion of the hydrograph and a larger one for the lower portion. See Example 1.)

Tabulate corresponding values of \( H \) and \( Q \), as taken from the breach discharge reservoir water-surface elevation relation curve (step 32(f)) for values of \( Q \) ranging from \( P_\text{in} \) (item 7 of known data) to \( Q_\text{in} \) (step 12).

Determine the idealized reservoir storage curve as follows: Select a series of values of reservoir water-surface elevations \( H \) ranging from \( H_c \) (step 13(c)) to \( H_\text{in} \) (item 3 of known data). For each value of \( H \):

(a) Compute \( H/H_\text{in} \).

(b) Determine from Plate 8 the storage factor \( R \) corresponding to \( H/H_\text{in} \).

(c) Compute \( R S_\text{in} \) (\( S_\text{in} \): item 4 of known data). \( R S_\text{in} \) is the reservoir storage \( S \) at elevation \( H \).

(d) On graph paper plot corresponding values of \( S \) and \( H \), and draw a smooth curve through the plotted points. This is the idealized reservoir storage curve.

Tabulate values of reservoir storage \( S \) corresponding to the values of elevation \( H \) tabulated in step 34, using the reservoir storage curve (step 35).

Determine the reservoir-routing working curve as follows:

(a) For each value of \( H \) tabulated in steps 34 and 36, compute \( N = Q/2 + S/\Delta t \) (\( \Delta t \): step 33).
(b) On graph paper plot corresponding values of \( N \) and \( Q' \), and draw a smooth curve through the plotted points. This is the reservoir-routing curve for the time interval \( \Delta t \).

38 (a) Tabulate the values of \( P_n \) at the end of each time interval \( \Delta t \) (step 33), as taken from the fictitious inflow hydrograph (step 31(g)).

(b) Compute the average \( P_n \) during each interval.

(c) Using the level-pool routing procedure illustrated in Example 1, apply the reservoir-routing working curve (step 37(b)) to compute the outflow \( Q \) at the end of each time interval \( \Delta t \).

(d) Compute the time after breaching \( t \) at which each outflow occurs by adding the number of preceding time intervals \( \Delta t \).

39 Plot corresponding values of outflow \( Q \) and time after breaching \( t \) (step 38) on graph paper and draw a smooth curve through the plotted points. Extend the curve down to the value \( Q = P_0 \) (item 7 of known data). (If the last computed outflow in step 38(c) is reasonably close to \( P_0 \), this extension may be done by eye; if not, the computation in step 38(a) thru (d) should be extended.) This is the breach outflow hydrograph for a medium breach.

40 To check approximately the preceding computations, proceed as follows:

(a) Measure or compute the volume of the fictitious inflow hydrograph (step 31(g)).

(b) Compute \( h = pH_0 \) and \( H_0 - h \) (\( p \): step 10; \( H_0 \): item 3 of known data) (\( h \) is the height of the negative wave).

(c) Using the reservoir storage curve (step 35(d)) compute the storage between elevations \( H_0 \) and \( H_0 - h \). To this value add \( P_0 t \), where \( t \) is the duration of the fictitious inflow hydrograph (step 31(g)).

(d) Compute the volume of the breach outflow hydrograph (step 38, as extended in step 39).

(e) Using the reservoir storage curve, compute the storage between elevations \( H_0 \) and \( H_e \) (step 12(c)). To this value add \( P_0 t \), where \( t \) is the duration of the breach outflow hydrograph.

(f) The results of steps (a) and (c) should be approximately equal, as should those of (d) and (e).

i. Large-breach procedure

41 Compute the average submerged-breached discharge rating curve as follows:
Select a series of values of discharge Q ranging from $P_0$ (item 7 of known data) to $Q_0$ (step 18(i)).

For each value of Q:

1. On the tailwater rating curve (step 13(a)) determine the value $H_d$ corresponding to Q and compute $h_d = H_d - H_c$ ($H_c$: step 13(c)).

2. Select a trial submergence ratio $\beta_1$.

3. Compute $Q/\beta_1$.

4. On the breach rating curve labeled $\beta = 1.00$ (step 15(c)) determine the value of k corresponding to $Q/\beta_1$.

5. Compute $h_d/k$.

6. On Plate 7 read the value of $\beta_2$ corresponding to $h_d/k$.

7. If $\beta_1$ does not equal $\beta_2$, select a new trial value $\beta_1$ and repeat steps (2) to (6). (If necessary, curves corresponding to those of step 18(h) can be drawn to determine $\beta_1 = \beta_2$, but are not usually required.)

On graph paper plot corresponding values of Q and k (as finally determined in step 41(b)(7)) and draw a smooth curve through the plotted points. This is the average submerged-breach discharge rating curve.

Compute the height of the steep negative wave $h'$ and the ratio $p' = h'/H_0$ as follows:

(a) Enter the curve showing the relation between discharge Q and velocity head $\Delta k$ (step 16(g)) to obtain the value of $\Delta k$ corresponding to $Q_0'$ (step 18(i)).

(b) Compute $h' = h_0 - k + \Delta k$ ($h_0$: item 1 of known data; k: step 18(i)).

(c) Compute $p' = h'/H_0$ ($H_0$: item 3 of known data).

Determine the fictitious inflow hydrograph as follows:

(a) Enter Plate 12 with the values of $p'$ (step 42(c)) and w (step 7) to obtain for each of a series of values of x ranging from 1 to $p'/2$ the corresponding value of $f(x,p',w) = x(x-p'/2)^{0.5} - w/x$.

(b) For each value of x compute $P_w = p'B_0H_0(gH_0)^{0.5}f(x,p',w)$. ($B_0H_0(gH_0)^{0.5}$: step 6).
(c) For each value of \( x \) compute \( P_n = P_0 + P_w \). \( (P_0: \text{ item 7 of known data}) \).

(d) Enter Plate 13 with the same values of \( x, p', \) and \( w \) used in (a) to obtain corresponding values of \( F(x, p', w) = t(gH_0)^{0.5}/L \).

(e) Compute \( L/(gH_0)^{0.5} \), obtaining \( (gH_0)^{0.5} \) from Plate 3a or Plate 3b (corresponding to the system of measurement used) \( (L, H_0: \text{ items 5 and 3 of known data}) \).

(f) Multiply each value of \( F(x, p', w) \) by \( L/(gH_0)^{0.5} \) to obtain \( t \). Also, compute the time \( t \) at which \( P_n = P_0 \) by the formula \( t = 2L/[(gH_0)^{0.5}(1 - w)] \).

(g) Plot on graph paper values of \( P_n \) and \( t \) corresponding to the same values of \( x \), and draw a smooth curve through the plotted points. If the value of \( P_n \) at \( t = 0 \) is not equal to \( Q_0' \) \( (\text{step 18(i)}) \), adjust the curve to pass through \( Q_0' \) at \( t = 0 \). This is the fictitious inflow hydrograph.

44 Determine the relation between submerged-breach discharge and reservoir water-surface elevation as follows:

(a) Select a series of values of discharge \( Q \) ranging from \( P_0 \) \( (\text{item 7 of known data}) \) to \( Q_0' \) \( (\text{step 18(i)}) \).

(b) For each value of \( Q \):

1. Determine the corresponding value of \( k \) from the average submerged-breach rating curve \( (\text{step 41(c)}) \).

2. Determine the corresponding value of \( \Delta k \) from the curve showing the relation between discharge and velocity head \( (\text{step 16(g)}) \).

3. Compute \( H = H_C + k - \Delta k \) \( (H_C: \text{ step 13(c)}) \).

(c) Plot corresponding values of \( Q \) and \( H \) on graph paper and draw a smooth curve through the plotted points. This is the relation between submerged-breach discharge and reservoir water-surface elevation.

45 By inspection of the fictitious inflow hydrograph \( (\text{step 43(g)}) \) determine the time interval \( \Delta t \) for which values of \( P_n \) adequately define the hydrograph. (Ordinarily, in order to expedite later computations, two values of \( \Delta t \) are used: one for the upper portion of the hydrograph and a larger one for the lower portion. See Example 2.)
46 Tabulate corresponding values of H and Q, as taken from the submerged-breach discharge reservoir water-surface elevation curve (step 44(c)) for values of Q ranging from P₀ (item 7 of known data) to Q₀ (step 18(i)).

47 Determine the idealized reservoir storage curve as follows: Select a series of values of reservoir water-surface elevations H ranging from H₀ (step 13(c)) to H₀ (item 3 of known data). For each value of H:

(a) Compute H/H₀.
(b) Determine from Plate 8 the storage factor R corresponding to H/H₀.
(c) Compute RS₀. (S₀: item 4 of known data). (RS₀ is the reservoir storage S at elevation H.)
(d) On graph paper plot corresponding values of S and H and draw a smooth curve through the plotted points. This is the idealized reservoir storage curve.

48 Tabulate values of reservoir storage S corresponding to the values of elevation H tabulated in step 46, using the reservoir storage curve (step 47(d)).

49 Determine the reservoir-routing working curve as follows:

(a) For each value of H tabulated in steps 46 and 48, compute N = Q/2 + S/Δt (Δt: step 45).
(b) On graph paper plot corresponding values of N and Q, and draw a smooth curve through the plotted points. This is the reservoir-routing curve for the time interval Δt.

50 (a) Tabulate the values of Pₙ at the end of each time interval Δt (step 45) as taken from the fictitious inflow hydrograph (step 43(g)).
(b) Compute the average Pₙ during each interval.
(c) Using the level-pool routing procedure illustrated in Example 2 apply the reservoir-routing working curve (step 49(b)) to compute the outflow Q at the end of each time interval Δt.
(d) Compute the time after breaching t at which each outflow occurs by adding the number of preceding time intervals Δt.

51 Plot corresponding values of outflow Q and time after breaching t (step 50(c) and (d)) on graph paper and draw a smooth curve through the plotted points. Extend the curve down to the value Q = P₀ (item 7 of
known data). (If the last computed outflow in step 50(c) is reasonably close to $P_0$, this extension may be done by eye; if not, the computation in step 50 should be extended.) This is the breach outflow hydrograph for a large breach.

52 To check approximately the preceding computations, proceed as follows:

(a) Compute the volume of the fictitious inflow hydrograph (step 43(g)).

(b) Using the reservoir storage curve (step 47(d)) compute the storage between elevations $H_Q$ and $H_Q - h' - (H_0$: item 3 of known data; $h'$: step 42(b)). To this value add $P_0 t$, where $t$ is the duration of the fictitious inflow hydrograph (step 43(g)).

(c) Compute the volume of the breach outflow hydrograph (step 50, as extended in step 51).

(d) Using the reservoir storage curve, compute the storage between elevations $H_Q$ and $H_C$ (step 13(c)). To this value add $P_0 t$, where $t$ is the duration of the breach outflow hydrograph (step 51).

(e) The results of steps (a) and (b) should be approximately equal, as should also those of (c) and (d).
CHAPTER 4
EXAMPLES OF PROCEDURE

Example 1 (Medium Breach)

a. General. This example illustrates the procedure for a medium breach. The character of the breach is developed as a part of the procedure for determining the outflow hydrograph.

b. Given data. Cross sections of the breach and the reservoir at the dam are shown on Plate 15. At the time of breaching, the water-surface elevation of the reservoir is 100 m above the bottom of the reservoir at the dam, and 75 m above the bottom of the breach. At the time of breaching, the reservoir is 50 km long and contains 1,580 million m³ of water. The rate of inflow to the reservoir is estimated to be 10,000 m³/sec.

The tailwater discharge rating curve is shown on Plate 16. Metric units are to be used in determining the outflow hydrograph. In a form corresponding to that shown in paragraph 13, the data assumed to be known are as follows:

<table>
<thead>
<tr>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ( h_0 ) = 75 m</td>
</tr>
<tr>
<td>2. See Plate 15, Cross Section of Breach</td>
</tr>
<tr>
<td>3. ( H_0 ) = 100 m</td>
</tr>
<tr>
<td>4. ( S_0 ) = 1,580 ( \times ) 10⁶ m³</td>
</tr>
<tr>
<td>5. ( L ) = 50,000 m</td>
</tr>
<tr>
<td>6. See Plate 15, Cross Section of Reservoir at Dam</td>
</tr>
<tr>
<td>7. ( P_0 ) = 10,000 m³/sec</td>
</tr>
<tr>
<td>8. See Plate 16, Tailwater Rating Curve</td>
</tr>
<tr>
<td>9. Metric system</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. ( P_0 ) = 3(1,580 ( \times ) 10⁶) / (50,000 ( \times ) 100) = 950 m</td>
</tr>
<tr>
<td>11. ( B_0 ) = 3,000,000 m³/sec (Enter nomograph with ( B_0 ) = 95m; multiply value on ( B_0 ) scale by 10.)</td>
</tr>
<tr>
<td>12. ( w ) = 10,000 / 3,000,000 = 0.003 (Use ( w ) = 0)</td>
</tr>
<tr>
<td>13. ( s ) = 75 / 100 = 0.75</td>
</tr>
<tr>
<td>14. ( m ) = 0.545 ( \times ) 615 / 950 = 0.353</td>
</tr>
<tr>
<td>15. ( p ) = 0.170</td>
</tr>
<tr>
<td>16. ( f(p,w) ) = 0.162</td>
</tr>
<tr>
<td>17. ( Q_0 ) = 10,000 + 3,000,000(0.162) = 496,000 m³/sec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conversion of units of measurement unnecessary</td>
</tr>
<tr>
<td>2</td>
<td>( B_{max} = 650 \text{ m}; A_{max} = 47,100 \text{ m}^2; h_m = 47,100/650 = 72.5 \text{ m} )</td>
</tr>
<tr>
<td>3</td>
<td>( Q_{max} = 690,000 \text{ m}^3/\text{sec} ) (Enter nomograph with ( B_{max} = 65m ); multiply value on ( Q_{max} ) scale by 10.)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( x )</th>
<th>( f(x,p,w) )</th>
<th>( P_n )</th>
<th>( P_n = P_w + 10,000 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.953</td>
<td>486,000</td>
<td>496,000</td>
</tr>
<tr>
<td>0.9</td>
<td>0.815</td>
<td>416,000</td>
<td>426,000</td>
</tr>
<tr>
<td>0.8</td>
<td>0.678</td>
<td>346,000</td>
<td>356,000</td>
</tr>
<tr>
<td>0.7</td>
<td>0.558</td>
<td>284,000</td>
<td>294,000</td>
</tr>
<tr>
<td>0.6</td>
<td>0.430</td>
<td>220,000</td>
<td>230,000</td>
</tr>
<tr>
<td>0.5</td>
<td>0.325</td>
<td>166,000</td>
<td>176,000</td>
</tr>
<tr>
<td>0.4</td>
<td>0.225</td>
<td>115,000</td>
<td>125,000</td>
</tr>
<tr>
<td>0.3</td>
<td>0.140</td>
<td>71,400</td>
<td>81,400</td>
</tr>
<tr>
<td>0.2</td>
<td>0.070</td>
<td>35,700</td>
<td>45,700</td>
</tr>
<tr>
<td>0.085</td>
<td>0.010</td>
<td>5,100</td>
<td>15,100</td>
</tr>
</tbody>
</table>
(d) thru (f) \((gH_0)^{0.5} = 31.3 \text{ m/sec} \); 
\[ \frac{L}{(gH_0)^{0.5}} = \frac{50,000}{31.3} = 1,600 \text{ sec} \]

<table>
<thead>
<tr>
<th>( x )</th>
<th>( F(x, p, w) )</th>
<th>( t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.9</td>
<td>0.110</td>
<td>176</td>
</tr>
<tr>
<td>0.8</td>
<td>0.220</td>
<td>352</td>
</tr>
<tr>
<td>0.7</td>
<td>0.340</td>
<td>545</td>
</tr>
<tr>
<td>0.6</td>
<td>0.475</td>
<td>760</td>
</tr>
<tr>
<td>0.5</td>
<td>0.620</td>
<td>990</td>
</tr>
<tr>
<td>0.4</td>
<td>0.785</td>
<td>1260</td>
</tr>
<tr>
<td>0.3</td>
<td>0.980</td>
<td>1570</td>
</tr>
<tr>
<td>0.2</td>
<td>1.230</td>
<td>1970</td>
</tr>
<tr>
<td>0.085</td>
<td>1.765</td>
<td>2820</td>
</tr>
</tbody>
</table>

(g) See Plate 17.

32 (a) thru (e)

<table>
<thead>
<tr>
<th>( Q ) ( m^3/sec )</th>
<th>( Q/B_o )</th>
<th>( D )</th>
<th>( k )</th>
<th>( k + H_c )</th>
<th>( H )</th>
<th>( H^2 )</th>
<th>( D/H^2 )</th>
<th>( H + D/H^2 )</th>
<th>( H )</th>
<th>( H^2 )</th>
<th>( D/H^2 )</th>
<th>( H + D/H^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>10.5</td>
<td>6</td>
<td>4.5</td>
<td>29.5</td>
<td>29.4</td>
<td>865</td>
<td>.01</td>
<td>29.4</td>
<td>29.5</td>
<td>870</td>
<td>.01</td>
<td>29.5</td>
</tr>
<tr>
<td>50,000</td>
<td>52.6</td>
<td>148</td>
<td>13.0</td>
<td>38.0</td>
<td>37.5</td>
<td>1406</td>
<td>.1</td>
<td>37.6</td>
<td>37.9</td>
<td>1435</td>
<td>.1</td>
<td>38.0</td>
</tr>
<tr>
<td>100,000</td>
<td>105.</td>
<td>600</td>
<td>20.8</td>
<td>45.8</td>
<td>45.5</td>
<td>2070</td>
<td>.3</td>
<td>45.8</td>
<td>45.5</td>
<td>2070</td>
<td>.3</td>
<td>45.8</td>
</tr>
<tr>
<td>200,000</td>
<td>210.</td>
<td>2300</td>
<td>32.9</td>
<td>57.9</td>
<td>56.0</td>
<td>3136</td>
<td>.7</td>
<td>56.7</td>
<td>57.2</td>
<td>3270</td>
<td>.7</td>
<td>57.9</td>
</tr>
<tr>
<td>300,000</td>
<td>316.</td>
<td>5300</td>
<td>43.5</td>
<td>68.5</td>
<td>65.0</td>
<td>4225</td>
<td>1.3</td>
<td>66.3</td>
<td>67.3</td>
<td>4530</td>
<td>1.2</td>
<td>68.5</td>
</tr>
<tr>
<td>400,000</td>
<td>421.</td>
<td>9500</td>
<td>52.5</td>
<td>77.5</td>
<td>73.0</td>
<td>5330</td>
<td>1.8</td>
<td>74.8</td>
<td>75.8</td>
<td>5740</td>
<td>1.7</td>
<td>77.5</td>
</tr>
<tr>
<td>496,000</td>
<td>522</td>
<td>14600</td>
<td>60.6</td>
<td>85.6</td>
<td>81.0</td>
<td>6560</td>
<td>2.2</td>
<td>83.2</td>
<td>83.5</td>
<td>6990</td>
<td>2.1</td>
<td>85.6</td>
</tr>
</tbody>
</table>

* Use nomograph with values 1/10 \( B \) and 1/10 \( Q \) and read \( k \) direct. The value \( k = 4.5 \) m for \( Q = 10,000 \) \( m^3/sec \) was determined by dividing the \( k \) value for \( Q = 100,000 \) \( m^3/sec \) by the factor \( 4.64 \) (\( \approx 10^{2/3} \)).

(f) See Plate 18.
\( \Delta t_1 = 200 \text{ sec for first 3,200 sec; } \Delta t_2 = 500 \text{ sec thereafter} \)

<table>
<thead>
<tr>
<th>( Q )</th>
<th>( H )</th>
<th>( \frac{Q}{2} )</th>
<th>( s )</th>
<th>( \frac{S}{200} )</th>
<th>( N_1 = \frac{Q}{2} + \frac{S}{200} )</th>
<th>( \frac{S}{500} )</th>
<th>( N_2 = \frac{Q}{2} + \frac{S}{500} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 1 \times 10^3 \text{ m}^3/\text{sec} )</td>
<td>( 10^6 \text{ m}^3 )</td>
<td>( 10^3 \text{ m}^3/\text{sec} )</td>
<td>( 10^3 \text{ m}^3/\text{sec} )</td>
<td>( \text{sec} )</td>
<td>( \text{sec} )</td>
<td>( \text{sec} )</td>
<td>( \text{sec} )</td>
</tr>
<tr>
<td>29.5</td>
<td>10 5</td>
<td>190</td>
<td>950</td>
<td>955</td>
<td>380</td>
<td>385</td>
<td></td>
</tr>
<tr>
<td>37.9</td>
<td>50 25</td>
<td>300</td>
<td>1500</td>
<td>1525</td>
<td>600</td>
<td>625</td>
<td></td>
</tr>
<tr>
<td>46.2</td>
<td>100 50</td>
<td>630</td>
<td>2150</td>
<td>2200</td>
<td>860</td>
<td>910</td>
<td></td>
</tr>
<tr>
<td>57.2</td>
<td>200 100</td>
<td>630</td>
<td>3150</td>
<td>3250</td>
<td>1260</td>
<td>1360</td>
<td></td>
</tr>
<tr>
<td>67.3</td>
<td>300 150</td>
<td>840</td>
<td>4200</td>
<td>4350</td>
<td>1680</td>
<td>1830</td>
<td></td>
</tr>
<tr>
<td>75.8</td>
<td>400 200</td>
<td>1020</td>
<td>5100</td>
<td>5300</td>
<td>2040</td>
<td>2240</td>
<td></td>
</tr>
<tr>
<td>83.5</td>
<td>496 248</td>
<td>1190</td>
<td>5950</td>
<td>6200</td>
<td>2380</td>
<td>2630</td>
<td></td>
</tr>
</tbody>
</table>

(a) thru (c)

(b) See Plate 20.

(d) See Plate 19.
Explanatory notes:

(1) In first line of table, set \( Q = P_n = 496 \)

(2) In first line of table, obtain value \( N_1 = 6,200 \) by entering reservoir-routing working curve (Plate 20) with the value \( Q = 496 \).

(3) In second line, \( N_1 = 6,167 = 6,200 - 496 + 463 \).

(4) In second line, obtain value \( Q = 493 \) by entering reservoir-routing working curve with the value \( N_1 = 6,167 \).

(5) In remainder of table, values of \( N \) and \( Q \) are obtained in the same way as those in line 2.

---

See Plate 21. This is the required solution of the outflow hydrograph.

(a) Volume, fictitious inflow hydrograph: \( 534 \times 10^6 \text{m}^3 \)

(b) \( h = 0.170 \times 100 = 17 \text{ m}; \ H_0 - h = 100 - 17 = 83 \text{ m} \)

(c) Storage at \( H = 100: \) \( 1580 \times 10^6 \text{m}^3 \)

Storage at \( H = 83: \) \( 1140 \times 10^6 \text{m}^3 \)

Net storage: \( 440 \times 10^6\text{m}^3 \)

\( P_{0t} = 10,000 \times 11,200 = 112 \times 10^6 \text{m}^3 \)

Total: \( 552 \times 10^6 \text{m}^3 \) (Checks with (a))

(d) Area under breach outflow hydrograph: \( 1540 \times 10^6 \text{m}^3 \)

(e) Storage at \( H = 100: \) \( 1580 \times 10^6 \text{m}^3 \)

Storage at \( H = 25: \) \( 136 \times 10^6 \text{m}^3 \)

Net storage: \( 1444 \times 10^6 \text{m}^3 \)

\( P_{0t} = 10,000 \times 12,700; 127 \times 10^6 \text{m}^3 \)

Total: \( 1571 \times 10^6 \text{m}^3 \) (Checks with (d))
Example 2 (Large Breach)

a. General. In this example the dimensions of the dam, breach, and reservoir are the same as in Example 1, but the tailwater rating curve is higher. As a result, tailwater submergence is shown to have a significant effect on breach outflow and the large-breach procedure must be used.

b. Given data. The dam, breach, and reservoir are the same as those of Example 1, with the same reservoir elevation, length, and total storage at time of breaching and the same rate of reservoir inflow. The tailwater discharge rating curve is that shown on Plate 22. Metric units are to be used in determining the outflow hydrograph. In a form corresponding to that shown in paragraph 13, the data assumed to be known are as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$h = 75$ m</td>
</tr>
<tr>
<td>2.</td>
<td>See Plate 15, Cross Section of Breach.</td>
</tr>
<tr>
<td>3.</td>
<td>$H_o = 100$ m</td>
</tr>
<tr>
<td>4.</td>
<td>$S_o = 1,580 \times 10^6$ m$^3$</td>
</tr>
<tr>
<td>5.</td>
<td>$L = 50,000$ m</td>
</tr>
<tr>
<td>6.</td>
<td>See Plate 15, Cross Section of Reservoir at Dam.</td>
</tr>
<tr>
<td>7.</td>
<td>$P_o = 10,000$ m$^3$/sec</td>
</tr>
<tr>
<td>8.</td>
<td>See Plate 22, Tailwater Rating Curve</td>
</tr>
<tr>
<td>9.</td>
<td>Metric system</td>
</tr>
</tbody>
</table>

c. Determination of breach outflow hydrograph. The step-by-step determination of the breach outflow hydrograph, based on the procedures given in paragraph 14, is as follows:

<table>
<thead>
<tr>
<th>Step</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conversion of units of measurement unnecessary</td>
</tr>
<tr>
<td>2</td>
<td>$B_{max} = 650$ m; $A_{max} = 47,100$ m$^2$; $h = 47,100/650 = 72.5$ m</td>
</tr>
<tr>
<td>3</td>
<td>$Q_{max} = 690,000$ m$^3$/sec (Enter nomograph with $B_{max} = 65$ m; multiply value on $Q_{max}$ scale by 10.)</td>
</tr>
<tr>
<td>4</td>
<td>$B = 615$ m</td>
</tr>
<tr>
<td>5</td>
<td>$B_o = 3 \left(1,580 \times 10^6\right) / \left(50,000 \times 100\right) = 950$ m</td>
</tr>
<tr>
<td>6</td>
<td>$B_o H_o (gH_o)^{0.5} = 3,000,000$ m$^3$/sec (Enter nomograph with $B_o = 95$ m; multiply value on $B_o H_o (gH_o)^{0.5}$ scale by 10.)</td>
</tr>
<tr>
<td>7</td>
<td>$w = 10,000/3,000,000 = 0.003$ (Use $w = o$)</td>
</tr>
<tr>
<td>8</td>
<td>$s = 75/100 = 0.75$</td>
</tr>
<tr>
<td>9</td>
<td>$m = 0.545 \times 615/950 = 0.353$</td>
</tr>
<tr>
<td>10</td>
<td>$p = 0.170$</td>
</tr>
<tr>
<td>11</td>
<td>$f(p, w) = 0.162$</td>
</tr>
<tr>
<td>12</td>
<td>$Q_o = 10,000 + 3,000,000(0.162) = 496,000$ m$^3$/sec</td>
</tr>
<tr>
<td>13</td>
<td>(a) See Plate 22, Tailwater Rating Curve.</td>
</tr>
<tr>
<td>(b)</td>
<td>$H_d = 81$ m</td>
</tr>
<tr>
<td>(c)</td>
<td>$H_c = 100 - 75 = 25$ m</td>
</tr>
<tr>
<td>(d)</td>
<td>$H_d$ is greater than $H_c$; $h_d = 81 - 25 = 56$ m</td>
</tr>
<tr>
<td>14</td>
<td>(a) $k = 60.6$ m (Enter nomograph with the values $B/10 = 61.5$ and $Q_o/10 = 49,600$.)</td>
</tr>
<tr>
<td>(b)</td>
<td>$0.4 \times k = 24.2$ m</td>
</tr>
<tr>
<td>(c)</td>
<td>$h_d$ is greater than $0.4 \times k$ (56 $&gt; 24.2$). Compute third approximation.</td>
</tr>
<tr>
<td>15</td>
<td>(a) $Q_k$</td>
</tr>
<tr>
<td>(b)</td>
<td>$k$</td>
</tr>
<tr>
<td></td>
<td>$10^3$ m$^3$/sec ( m )</td>
</tr>
<tr>
<td>10</td>
<td>4.5</td>
</tr>
<tr>
<td>50</td>
<td>13.0</td>
</tr>
<tr>
<td>100</td>
<td>20.8</td>
</tr>
<tr>
<td>200</td>
<td>32.9</td>
</tr>
<tr>
<td>300</td>
<td>43.5</td>
</tr>
<tr>
<td>400</td>
<td>52.5</td>
</tr>
<tr>
<td>496</td>
<td>60.6</td>
</tr>
<tr>
<td>600</td>
<td>68.5</td>
</tr>
<tr>
<td>(c)</td>
<td>See Plate 23.</td>
</tr>
<tr>
<td>Q</td>
<td>k</td>
</tr>
<tr>
<td>----</td>
<td>-----</td>
</tr>
<tr>
<td>10,000</td>
<td>4.5</td>
</tr>
<tr>
<td>50,000</td>
<td>13.0</td>
</tr>
<tr>
<td>100,000</td>
<td>20.8</td>
</tr>
<tr>
<td>200,000</td>
<td>32.9</td>
</tr>
<tr>
<td>300,000</td>
<td>43.5</td>
</tr>
<tr>
<td>400,000</td>
<td>52.5</td>
</tr>
<tr>
<td>496,000</td>
<td>60.6</td>
</tr>
</tbody>
</table>

(g) See Plate 24.
17 (a) thru (f) $P_0 = 10,000 \text{ m}^3/\text{sec}$ $\omega = 0$ $B_B H_B (gH_B)^{0.5} = 3 \times 10^6$

<table>
<thead>
<tr>
<th>$p'$</th>
<th>$p'' (1-2)$</th>
<th>$q_a$</th>
<th>$h'$</th>
<th>$h'' - h'$</th>
<th>$\Delta k$</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>.085</td>
<td>.083</td>
<td>259,000</td>
<td>8.5</td>
<td>66.5</td>
<td>1.0</td>
<td>67.5</td>
</tr>
<tr>
<td>.10</td>
<td>.097</td>
<td>301,000</td>
<td>10.0</td>
<td>65.0</td>
<td>1.2</td>
<td>66.2</td>
</tr>
<tr>
<td>.125</td>
<td>.121</td>
<td>373,000</td>
<td>12.5</td>
<td>62.5</td>
<td>1.5</td>
<td>64.0</td>
</tr>
<tr>
<td>.150</td>
<td>.145</td>
<td>445,000</td>
<td>15.0</td>
<td>60.0</td>
<td>1.9</td>
<td>61.9</td>
</tr>
<tr>
<td>.170</td>
<td>.163</td>
<td>499,000</td>
<td>17.0</td>
<td>58.0</td>
<td>2.1</td>
<td>60.1</td>
</tr>
</tbody>
</table>

(g) See Plate 23

18 (a) (b)

First trial | Second trial | Third trial

<table>
<thead>
<tr>
<th>$k$</th>
<th>$Q$, $\beta_1 = 1.0$</th>
<th>$\beta_1' = .9$</th>
<th>$\beta_1'' = .8$</th>
<th>$\beta_1''' = .6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>68.5</td>
<td>600,000</td>
<td>540,000</td>
<td>480,000</td>
<td>360,000</td>
</tr>
<tr>
<td>60.6</td>
<td>496,000</td>
<td>446,000</td>
<td>396,000</td>
<td>297,000</td>
</tr>
<tr>
<td>52.5</td>
<td>400,000</td>
<td>360,000</td>
<td>320,000</td>
<td>240,000</td>
</tr>
<tr>
<td>43.5</td>
<td>300,000</td>
<td>270,000</td>
<td>240,000</td>
<td>180,000</td>
</tr>
</tbody>
</table>

(c) See Plate 23

(d) thru (g) $\beta_1' = .715$

First trial | Second trial | Third trial

<table>
<thead>
<tr>
<th>$\beta_1'' = 1.0$</th>
<th>$\beta_1' = .9$</th>
<th>$\beta_1'' = .8$</th>
<th>$\beta_1''' = .6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_a$ 499,000</td>
<td>459,000</td>
<td>418,000</td>
<td>329,000</td>
</tr>
<tr>
<td>$k$ 60.8</td>
<td>61.5</td>
<td>62.3</td>
<td>64.9</td>
</tr>
<tr>
<td>$H_d$ 82.0</td>
<td>77.0</td>
<td>72.1</td>
<td>61.5</td>
</tr>
<tr>
<td>$h_d$ 57.0</td>
<td>52.0</td>
<td>47.1</td>
<td>36.5</td>
</tr>
<tr>
<td>$h_d' = .938$</td>
<td>$.845$</td>
<td>$.756$</td>
<td>$.562$</td>
</tr>
<tr>
<td>$\beta_2$ .395</td>
<td>.561</td>
<td>.665</td>
<td>.809</td>
</tr>
</tbody>
</table>

18 h See Plate 25. At point of intersection of curves, $Q_a = 381,000 \text{ m}^3/\text{sec}$, $\beta = .715$

18 i Step repeated

(a), (b) $k$, $\beta_1' = 1.0$ $\beta_1 = .715$

<table>
<thead>
<tr>
<th>$k$</th>
<th>$Q$, $\beta_1' = 1.0$</th>
<th>$\beta_1 = .715$</th>
</tr>
</thead>
<tbody>
<tr>
<td>68.5</td>
<td>600,000</td>
<td>429,000</td>
</tr>
<tr>
<td>60.6</td>
<td>496,000</td>
<td>354,000</td>
</tr>
<tr>
<td>52.5</td>
<td>400,000</td>
<td>286,000</td>
</tr>
<tr>
<td>43.5</td>
<td>300,000</td>
<td>215,000</td>
</tr>
</tbody>
</table>

(c) See Plate 23.

(d) thru (g) $\beta_1' = .715$

| $Q_a$ 381,000 |
| $k$ 63.1 |
| $H_d$ 68.3 |
| $h_d$ 43.3 |
| $h_d'$ .686 |
| $\beta_2$ .724 (approximately checks $\beta_1'$) |

$Q_a' = Q_a = 381,000 \text{ m}^3/\text{sec}$ at $k = 63.1 \text{ m}$.

19 Omitted

20 (b) $90\% Q_a = 0.9 \times 496,000 = 446,000 \text{ m}^3/\text{sec}$. $Q_o' = 381,000 \text{ m}^3/\text{sec}$

21 $Q_o'$ is less than $90\% Q_o$ Use large-breach procedure.

22 - 40 Omitted
41 (a) (b) $Q = 300,000 \text{ m}^3/\text{sec}; H_d = 58.0 \text{ m}; h_d = 58.0 - 25.0 = 33.0 \text{ m}$

<table>
<thead>
<tr>
<th>Trial</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$\beta_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q$</td>
<td>429,000</td>
<td>406,000</td>
<td>395,000</td>
</tr>
<tr>
<td>$k$</td>
<td>54.9</td>
<td>52.8</td>
<td>52.0</td>
</tr>
<tr>
<td>$h_d$</td>
<td>.602</td>
<td>.625</td>
<td>.635</td>
</tr>
<tr>
<td>$k$</td>
<td>.785</td>
<td>.770</td>
<td>.765</td>
</tr>
</tbody>
</table>

$Q = 100,000 \text{ m}^3/\text{sec}; H_d = 27.0 \text{ m}; h_d = 27.0 - 25.0 = 2.0 \text{ m}$

<table>
<thead>
<tr>
<th>Trial</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$\beta_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q$</td>
<td>111,000</td>
<td>105,000</td>
<td>102,000</td>
</tr>
<tr>
<td>$k$</td>
<td>22.1</td>
<td>21.3</td>
<td>20.9</td>
</tr>
<tr>
<td>$h_d$</td>
<td>.090</td>
<td>.094</td>
<td>.096</td>
</tr>
<tr>
<td>$k$</td>
<td>.980</td>
<td>.980</td>
<td>.980</td>
</tr>
</tbody>
</table>

41 (a) (b) continued

$Q = 200,000 \text{ m}^3/\text{sec}; H_d = 43.7 \text{ m}; h_d = 43.7 - 25.0 = 18.7 \text{ m}$

<table>
<thead>
<tr>
<th>Trial</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$\beta_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q$</td>
<td>286,000</td>
<td>250,000</td>
<td>238,000</td>
</tr>
<tr>
<td>$k$</td>
<td>41.7</td>
<td>38.1</td>
<td>37.0</td>
</tr>
<tr>
<td>$h_d$</td>
<td>.449</td>
<td>.491</td>
<td>.505</td>
</tr>
<tr>
<td>$k$</td>
<td>.870</td>
<td>.850</td>
<td>.840</td>
</tr>
</tbody>
</table>

$Q = 50,000 \text{ m}^3/\text{sec}; H_d = 16.5 \text{ m}; 16.5 < 25.0; \text{ no submergence.}$

(c) $Q$

<table>
<thead>
<tr>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>381,000</td>
</tr>
<tr>
<td>300,000</td>
</tr>
<tr>
<td>200,000</td>
</tr>
</tbody>
</table>

$k$ is the same as on $\beta = 1$ curve.

See Plate 26.

42 (a) When $Q' = 381,000 \text{ m}^3/\text{sec}; \Delta k = 1.6 \text{ m}$, to nearest tenth

(b) $h' = 75.0 - 63.1 + 1.6 = 13.5 \text{ m}$

(c) $p' = 13.5/100 = 0.135$
43 (a) thru (c) \( p' H_0 B_0 (gH_0)^{0.5} = 0.135 \times 3 \times 10^6 = 405 \times 10^3 \)

<table>
<thead>
<tr>
<th>( x )</th>
<th>( f(x,p',w) )</th>
<th>( P_{w3} ) m/ sec</th>
<th>( P ) m(^3)/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>.960</td>
<td>388,000</td>
<td>398,000</td>
</tr>
<tr>
<td>.8</td>
<td>.685</td>
<td>278,000</td>
<td>288,000</td>
</tr>
<tr>
<td>.6</td>
<td>.435</td>
<td>176,000</td>
<td>186,000</td>
</tr>
<tr>
<td>.4</td>
<td>.230</td>
<td>93,500</td>
<td>103,000</td>
</tr>
<tr>
<td>.2</td>
<td>.070</td>
<td>28,400</td>
<td>38,400</td>
</tr>
<tr>
<td>.1</td>
<td>.015</td>
<td>6,100</td>
<td>16,100</td>
</tr>
</tbody>
</table>

(d) thru (f) \( (gH_0)^{0.5} = 31.3 \) \( L = 50,000 \) \( L (gH_0)^{0.5} = 1600 \)

<table>
<thead>
<tr>
<th>( x )</th>
<th>( P(x,p',w) ) sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>190</td>
</tr>
<tr>
<td>.8</td>
<td>120</td>
</tr>
<tr>
<td>.6</td>
<td>75</td>
</tr>
<tr>
<td>.4</td>
<td>47</td>
</tr>
<tr>
<td>.2</td>
<td>1.20</td>
</tr>
<tr>
<td>.1</td>
<td>1.50</td>
</tr>
</tbody>
</table>

44 (a) (b) \( H = 25 \) m

<table>
<thead>
<tr>
<th>( Q ) m(^3)/sec</th>
<th>( k ) m</th>
<th>( \Delta k ) m</th>
<th>( H ) m</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>4.0</td>
<td>.01</td>
<td>29.0</td>
</tr>
<tr>
<td>50,000</td>
<td>13.0</td>
<td>.1</td>
<td>37.9</td>
</tr>
<tr>
<td>100,000</td>
<td>21.0</td>
<td>.3</td>
<td>45.7</td>
</tr>
<tr>
<td>200,000</td>
<td>37.0</td>
<td>.7</td>
<td>61.3</td>
</tr>
<tr>
<td>300,000</td>
<td>52.0</td>
<td>1.2</td>
<td>75.8</td>
</tr>
<tr>
<td>381,000</td>
<td>63.1</td>
<td>1.6</td>
<td>86.5</td>
</tr>
</tbody>
</table>

(c) See Plate 28.

45 \( \Delta t_1 = 200 \) sec; \( \Delta t_2 = 1,000 \) sec

46 Q \( H \)

<table>
<thead>
<tr>
<th>( m^3/sec )</th>
<th>( m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>29.0</td>
</tr>
<tr>
<td>50,000</td>
<td>37.9</td>
</tr>
<tr>
<td>100,000</td>
<td>45.7</td>
</tr>
<tr>
<td>200,000</td>
<td>61.3</td>
</tr>
<tr>
<td>300,000</td>
<td>75.8</td>
</tr>
<tr>
<td>381,000</td>
<td>86.5</td>
</tr>
</tbody>
</table>

47 (a) thru (c)

48 H \( S \)

<table>
<thead>
<tr>
<th>( m )</th>
<th>( 10^6 ) m(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.0</td>
<td>175</td>
</tr>
<tr>
<td>37.9</td>
<td>300</td>
</tr>
<tr>
<td>45.7</td>
<td>425</td>
</tr>
<tr>
<td>61.3</td>
<td>700</td>
</tr>
<tr>
<td>75.8</td>
<td>1020</td>
</tr>
<tr>
<td>86.5</td>
<td>1255</td>
</tr>
</tbody>
</table>

49 (a)

<table>
<thead>
<tr>
<th>( H )</th>
<th>( Q ) m(^3)/sec</th>
<th>( Q/2 ) m(^3)/sec</th>
<th>( S ) m(^3)</th>
<th>( S/200 ) m(^3)</th>
<th>( N_1 = Q/2 + S/200 ) m(^3)</th>
<th>( S/1000 ) m(^3)</th>
<th>( N_2 = Q/2 + S/1000 ) m(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.0</td>
<td>10</td>
<td>5</td>
<td>175</td>
<td>875</td>
<td>880</td>
<td>175</td>
<td>180</td>
</tr>
<tr>
<td>37.9</td>
<td>50</td>
<td>25</td>
<td>1500</td>
<td>1525</td>
<td>300</td>
<td>325</td>
<td>475</td>
</tr>
<tr>
<td>45.7</td>
<td>100</td>
<td>50</td>
<td>425</td>
<td>2125</td>
<td>2175</td>
<td>425</td>
<td>475</td>
</tr>
<tr>
<td>61.3</td>
<td>200</td>
<td>100</td>
<td>700</td>
<td>3500</td>
<td>3600</td>
<td>700</td>
<td>800</td>
</tr>
<tr>
<td>75.8</td>
<td>300</td>
<td>150</td>
<td>1020</td>
<td>5100</td>
<td>5250</td>
<td>1020</td>
<td>1170</td>
</tr>
<tr>
<td>86.5</td>
<td>381</td>
<td>190</td>
<td>1255</td>
<td>6270</td>
<td>6460</td>
<td>1255</td>
<td>1445</td>
</tr>
</tbody>
</table>

(b) See Plate 30 a and b.
\[ \Delta t_1 = 200 \text{ sec} \]

<table>
<thead>
<tr>
<th>Interval</th>
<th>( 10^3 \text{m}^3/\text{sec} )</th>
<th>( \text{Pn} )</th>
<th>Avg ( \text{Pn} )</th>
<th>( N_1 )</th>
<th>( 10^3 \text{m}^3/\text{sec} )</th>
<th>( Q )</th>
<th>t sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>381</td>
<td>6460</td>
<td>381</td>
<td>0</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>320</td>
<td>6429</td>
<td>378</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>265</td>
<td>6343</td>
<td>373</td>
<td>400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>215</td>
<td>6210</td>
<td>365</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>173</td>
<td>6039</td>
<td>355</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>137</td>
<td>5839</td>
<td>340</td>
<td>1000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>105</td>
<td>5620</td>
<td>329</td>
<td>1200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>82</td>
<td>5385</td>
<td>313</td>
<td>1400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>63</td>
<td>5144</td>
<td>298</td>
<td>1600</td>
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<td></td>
</tr>
<tr>
<td>9</td>
<td>47</td>
<td>4901</td>
<td>283</td>
<td>1800</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>10</td>
<td>34</td>
<td>4658</td>
<td>268</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>25</td>
<td>4420</td>
<td>254</td>
<td>2200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>18</td>
<td>4188</td>
<td>238</td>
<td>2400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>12</td>
<td>3965</td>
<td>223</td>
<td>2600</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ \Delta t_2 = 1000 \text{ sec} \]

<table>
<thead>
<tr>
<th>( N_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

Explanatory notes:
1. In first line of table, set \( Q = P_n = 381 \).
2. In first line of table, obtain value \( N_1 = 6460 \)
   by entering reservoir-routing working curve (Plate 30) with the value \( Q = 381 \).
3. In second line, \( N_1 = 6,429 = 6,460 - 381 + 350 \).
4. In second line, obtain value \( Q = 378 \) by entering reservoir-routing working curve with the value \( N_1 = 6,429 \).
5. In the remainder of the table, values of \( N \) and \( Q \) are obtained in the same way as those in line 2.

---

51 See Plate 31. This is the required solution of the outflow hydrograph.

52 (a) Volume of fictitious inflow: \( 436 \times 10^6 \text{ m}^3 \)

(b) Storage at \( H = 100 \text{ m} \): \( 1580 \times 10^6 \text{ m}^3 \)
   Net storage: \( 318 \times 10^6 \text{ m}^3 \)
   \( P_0 t = 10,000 \times 12,600 = 126 \times 10^6 \text{ m}^3 \)
   Total: \( 444 \times 10^6 \text{ m}^3 \) (Checks with (a))

(c) Area under breach outflow hydrograph: \( 1510 \times 10^6 \text{ m}^3 \)

(d) Storage at \( H = 100 \text{ m} \): \( 1580 \times 10^6 \text{ m}^3 \)
   Storage at \( H = 25 \text{ m} \): \( 136 \times 10^6 \text{ m}^3 \)
   Net storage: \( 1444 \times 10^6 \text{ m}^3 \)
   \( P_0 t = 10,000 \times 15,700 = 157 \times 10^6 \text{ m}^3 \)
   Total: \( 1601 \times 10^6 \text{ m}^3 \) (Checks with (c))
Example 3 (Small Breach, Small Reservoir Inflow)

a. General. This example illustrates the procedure for a small breach with small reservoir inflow. The character of the breach, however, is not established until the effects of the negative wave and tailwater submergence have been determined to be negligible.

b. Given data. The dam and reservoir are the same as those of Example 1, with the same reservoir elevation, length, and total storage at time of breaching. The tailwater discharge rating curve is the same as in Example 1. (See Plate 16.) The breach, shown on Plate 32, has a top width of 250 m at the water level at time of breaching and a corresponding depth of 50 m. The estimated rate of reservoir inflow is 1,000 m³/sec. Metric units are to be used in determining the outflow hydrograph. In a form corresponding to that shown in paragraph 13, the data assumed to be known are as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$h_0 = 50$ m</td>
</tr>
<tr>
<td>2.</td>
<td>See Plate 32, Cross Section of Breach.</td>
</tr>
<tr>
<td>3.</td>
<td>$H_0 = 100$ m</td>
</tr>
<tr>
<td>4.</td>
<td>$S_0 = 1,580 \times 10^6$ m³</td>
</tr>
<tr>
<td>5.</td>
<td>$L = 50,000$ m</td>
</tr>
<tr>
<td>6.</td>
<td>See Plate 32, Cross Section of Reservoir at Dam.</td>
</tr>
<tr>
<td>7.</td>
<td>$P_0 = 1,000$ m³/sec</td>
</tr>
<tr>
<td>8.</td>
<td>See Plate 16, Tailwater Rating Curve.</td>
</tr>
<tr>
<td>9.</td>
<td>Metric system</td>
</tr>
</tbody>
</table>

Item | Solution
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>$p = 0.033$</td>
</tr>
<tr>
<td>11.</td>
<td>$f(p,w) = 0.032$</td>
</tr>
<tr>
<td>12.</td>
<td>$Q_0 = 1,000 + 3,000,000(0.032) = 97,000$ m³/sec</td>
</tr>
<tr>
<td>13. (a)</td>
<td>See Plate 16, Tailwater Rating Curve.</td>
</tr>
</tbody>
</table>

b. Determination of breach outflow hydrograph. The step-by-step determination of the breach outflow hydrograph, based on the procedures given in paragraph 14, is as follows:

<table>
<thead>
<tr>
<th>Step</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Conversion of units of measurement unnecessary</td>
</tr>
<tr>
<td>2.</td>
<td>$B_{\text{max}} = 250$ m; $A_{\text{max}} = 9,820$ m²; $h_m = 9820/250 = 39.3$ m</td>
</tr>
<tr>
<td>3.</td>
<td>$Q_{\text{max}} = 105,000$ m³/sec (Enter nomograph with $B_{\text{max}} = 25$ m; multiply value on $Q_{\text{max}}$ scale by 10.)</td>
</tr>
<tr>
<td>4.</td>
<td>$B = 175$ m (Enter nomograph with $Q_{\text{max}} = 10,500$ m³/sec; multiply value on $B$ scale by 10.)</td>
</tr>
<tr>
<td>5.</td>
<td>$B_0 = 3(1580)(10^6)/(50000)(100) = 950$ m</td>
</tr>
<tr>
<td>6.</td>
<td>$B_0H_0 (gH_0)^{0.5} = 3,000,000$ m³/sec (Enter nomograph with $B_0 = 95$ m; multiply value on $B_0H_0(gH_0)^{0.5}$ scale by 10.)</td>
</tr>
<tr>
<td>7.</td>
<td>$w = 1000/3,000,000 = 0.0003$ (Use $w = 0$.)</td>
</tr>
<tr>
<td>8.</td>
<td>$s = 50/100 = 0.50$</td>
</tr>
<tr>
<td>9.</td>
<td>$m = 0.545 \times 175/950 = 0.10$</td>
</tr>
<tr>
<td>10.</td>
<td>$p = 0.033$</td>
</tr>
<tr>
<td>11.</td>
<td>$f(p,w) = 0.032$</td>
</tr>
<tr>
<td>12.</td>
<td>$Q_0 = 1,000 + 3,000,000(0.032) = 97,000$ m³/sec</td>
</tr>
<tr>
<td>13. (a)</td>
<td>See Plate 16, Tailwater Rating Curve.</td>
</tr>
<tr>
<td>(b)</td>
<td>$H_d = 12.9$ m</td>
</tr>
<tr>
<td>(c)</td>
<td>$H_c = 100 - 50 = 50$ m</td>
</tr>
<tr>
<td>(d)</td>
<td>$H_d$ is less than $H_c$ (12.9 &lt; 50). Omit computation of third approximation.</td>
</tr>
<tr>
<td>14. - 18</td>
<td>Omitted</td>
</tr>
<tr>
<td>19.</td>
<td>$Q_0$ is greater than 90% $Q_{\text{max}}$ (97,000 &gt; 94,500). Use small-breach procedure.</td>
</tr>
<tr>
<td>20. - 21</td>
<td>Omitted</td>
</tr>
<tr>
<td>22. (a)</td>
<td>$H_c/H_0 = 50/100 = 0.50$</td>
</tr>
<tr>
<td>(b)</td>
<td>$R = 0.315$</td>
</tr>
<tr>
<td>(c)</td>
<td>$S_e = 1580 \times 10^6(0.685) = 1080 \times 10^6$ m³</td>
</tr>
<tr>
<td>23.</td>
<td>$c = 1.10$</td>
</tr>
<tr>
<td>24.</td>
<td>$t_k = 1080 \times 10^6 /105000 = 10,300$ sec</td>
</tr>
</tbody>
</table>
25 \( P \) is less than 10% \( Q_{\text{max}} \) (1,000 < 10,500). Follow procedure for small breaches with small reservoir inflow.

26 (a) thru (c)

<table>
<thead>
<tr>
<th>( Q/Q_{\text{max}} )</th>
<th>( t/t_k )</th>
<th>( t ) sec</th>
<th>( Q ) m³/sec</th>
<th>( Q_t ) m³/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0</td>
<td>0</td>
<td>105,000</td>
<td>106,000</td>
</tr>
<tr>
<td>0.90</td>
<td>0.07</td>
<td>720</td>
<td>94,500</td>
<td>95,500</td>
</tr>
<tr>
<td>0.80</td>
<td>0.17</td>
<td>1750</td>
<td>84,000</td>
<td>85,000</td>
</tr>
<tr>
<td>0.70</td>
<td>0.27</td>
<td>2780</td>
<td>73,500</td>
<td>74,500</td>
</tr>
<tr>
<td>0.60</td>
<td>0.40</td>
<td>4120</td>
<td>63,000</td>
<td>64,000</td>
</tr>
<tr>
<td>0.50</td>
<td>0.57</td>
<td>5870</td>
<td>52,500</td>
<td>53,500</td>
</tr>
<tr>
<td>0.40</td>
<td>0.76</td>
<td>7830</td>
<td>42,000</td>
<td>43,000</td>
</tr>
<tr>
<td>0.30</td>
<td>1.04</td>
<td>10710</td>
<td>31,500</td>
<td>32,500</td>
</tr>
<tr>
<td>0.20</td>
<td>1.46</td>
<td>15040</td>
<td>21,000</td>
<td>22,000</td>
</tr>
<tr>
<td>0.10</td>
<td>2.32</td>
<td>23900</td>
<td>10,500</td>
<td>11,500</td>
</tr>
<tr>
<td>0.05</td>
<td>3.40</td>
<td>35020</td>
<td>5,250</td>
<td>6,250</td>
</tr>
</tbody>
</table>

(d) See Plate 33. This is the required solution of the outflow hydrograph.

27 (a) \( \Sigma Q_t = 1040 \times 10^6 \text{m}^3 \) during first 40,000 sec

(b) \( S_e + P_0 t = 1080 \times 10^6 + 1000(40,000) = 1120 \times 10^6 \text{m}^3 \)

Results of (a) and (b) are approximately equal, thus checking the computations.
Example 4 (Small Breach, Appreciable Reservoir Inflow)

a. General. In this example the dimensions of the dam, breach, and reservoir are the same as in Example 3, but the rate of reservoir inflow is higher. The procedure shows that the small-breach procedure with appreciable reservoir inflow must be used.

b. Given data. The dam and reservoir are the same as those of Example 3, with the same reservoir elevation, length, and total storage at time of breaching. The tailwater discharge rating curve is the same as in Example 1. (See Plate 16.) The breach is the same as in Example 3. The estimated rate of reservoir inflow is 15,000 m$^3$/sec. Metric units are to be used in determining the outflow hydrograph. In a form corresponding to that shown in paragraph 13, the data assumed to be known are as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $h_0$</td>
<td>50 m</td>
</tr>
<tr>
<td>2. See Plate 32, Cross Section of Breach.</td>
<td></td>
</tr>
<tr>
<td>3. $H_o$</td>
<td>100 m</td>
</tr>
<tr>
<td>4. $S_0$</td>
<td>$1,580 \times 10^6$ m$^3$</td>
</tr>
<tr>
<td>5. $L$</td>
<td>50,000 m</td>
</tr>
<tr>
<td>6. See Plate 32, Cross Section of Reservoir at Dam.</td>
<td></td>
</tr>
<tr>
<td>7. $P_o$</td>
<td>15,000 m$^3$/sec</td>
</tr>
<tr>
<td>8. See Plate 16, Tailwater Rating Curve.</td>
<td></td>
</tr>
<tr>
<td>9. Metric system</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conversion of units of measurement unnecessary</td>
</tr>
<tr>
<td>2</td>
<td>$B_{max} = 250$ m; $A_{max} = 9,820$ m$^2$; $h_m = 9820/250 = 39.3$ m</td>
</tr>
<tr>
<td>3</td>
<td>$Q_{max} = 105,000$ m$^3$/sec (Enter nomograph with $B_{max} = 25$ m; multiply value on $Q_{max}$ scale by 10.)</td>
</tr>
<tr>
<td>4</td>
<td>$B = 175$ m (Enter nomograph with $Q_{max} = 10,500$ m$^3$/sec; multiply value on $B$ scale by 10.)</td>
</tr>
<tr>
<td>5</td>
<td>$B_o = 3(1580)(10^6)/(50000)(100) = 950$ m</td>
</tr>
<tr>
<td>6</td>
<td>$B_o H_o (g H_o)^{0.5} = 3,000,000$ m$^3$/sec (Enter nomograph with $B_o = 95$ m; multiply value on $B_o H_o (g H_o)^{0.5}$ scale by 10.)</td>
</tr>
<tr>
<td>7</td>
<td>$w = 15,000/3,000,000 = 0.005$ (Use $w = 0$.)</td>
</tr>
<tr>
<td>8</td>
<td>$s = 50/100 = 0.50$</td>
</tr>
<tr>
<td>9</td>
<td>$m = 0.545 \times 175/950 = 0.10$</td>
</tr>
<tr>
<td>10</td>
<td>$p = 0.033$</td>
</tr>
<tr>
<td>11</td>
<td>$f(p, w) = 0.032$</td>
</tr>
<tr>
<td>12</td>
<td>$Q_o = 15,000 + 3,000,000(0.032) = 111,000$ m$^3$/sec</td>
</tr>
</tbody>
</table>

(Note: $Q_o$ cannot exceed $Q_{max}$. The apparent discrepancy results from using the $w = 0$ curve in step 10 instead of the actual value $w = 0.005$. The computation using the value $w = 0.005$ gives $p = 0.028$ (step 10), $f(p, w) = 0.0276$ (step 11) and $Q = 15,000 + 3,000,000(0.0276) = 97,800$ m$^3$/sec (step 12). This difference is not sufficient to require a revision of the basic procedure.)
22 (a) $H_c/H_o = 50/100 = 0.50$

(b) $R = 0.315$

(c) $S_e = 1580(10^6) (0.685) = 1080 \times 10^6 \text{ m}^3$

23 $c = 1.10$

24 $t_k = 1080 \times 10^6 / 105000 = 10,300 \text{ sec}$

25 $P_0$ is greater than 10% $Q_{\text{max}} (15,000 > 10,500)$. Follow procedure for small breaches with appreciable reservoir inflow.

26 - 27 Omitted

28 $P_0/Q_{\text{max}} = 15,000/115,000 = 0.14$

29 (a), (b)

<table>
<thead>
<tr>
<th>$Q/Q_{\text{max}}$</th>
<th>$Q$</th>
<th>$t/t_k$</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m$^3$/sec</td>
<td></td>
<td>sec</td>
</tr>
<tr>
<td>1.00</td>
<td>105,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.90</td>
<td>94,500</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>0.80</td>
<td>84,000</td>
<td>0.19</td>
<td>0.21</td>
</tr>
<tr>
<td>0.70</td>
<td>73,500</td>
<td>0.31</td>
<td>0.34</td>
</tr>
<tr>
<td>0.60</td>
<td>63,000</td>
<td>0.47</td>
<td>0.51</td>
</tr>
<tr>
<td>0.50</td>
<td>52,500</td>
<td>0.66</td>
<td>0.72</td>
</tr>
<tr>
<td>0.40</td>
<td>42,000</td>
<td>0.95</td>
<td>1.03</td>
</tr>
<tr>
<td>0.30</td>
<td>31,500</td>
<td>1.40</td>
<td>1.54</td>
</tr>
<tr>
<td>0.25</td>
<td>26,250</td>
<td>2.00</td>
<td>20600</td>
</tr>
</tbody>
</table>

(c) See Plate 34. This is the required solution of the outflow hydrograph.

30 (a) $\Sigma Q = 1010 \times 10^6 \text{ m}^3$ during first 20,000 sec

(b) $S_e + P_0 t = 1080 \times 10^6 + 15000(20000) = 1380 \times 10^6 \text{ m}^3$

The results of (a) and (b) are approximately equal, taking into consideration the volume of flow ignored in (a), and approximately check the computations.
REFERENCES


## TABLE 1

**SYMBOLS**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>Coefficient in reservoir storage-elevation function ($S = ah^c$)</td>
</tr>
<tr>
<td>$A$</td>
<td>Area of reservoir cross section at dam</td>
</tr>
<tr>
<td>$A_{\text{max}}$</td>
<td>Area of breach below reservoir water surface at time of breaching</td>
</tr>
<tr>
<td>$b$</td>
<td>Coefficient in the breach outflow rating curve ($Q = bk^{1.5}$)</td>
</tr>
<tr>
<td>$B$</td>
<td>Width of idealized rectangular breach</td>
</tr>
<tr>
<td>$B_{\text{max}}$</td>
<td>Width of breach at reservoir water surface at time of breaching</td>
</tr>
<tr>
<td>$B_0$</td>
<td>Width of idealized rectangular reservoir at dam</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Submergence ratios which take into account the effect of tailwater depths on the outflow discharges</td>
</tr>
<tr>
<td>$\beta_1$, $\beta_2$</td>
<td>Submergence ratios which take into account the effect of tailwater depths on the outflow discharges</td>
</tr>
<tr>
<td>$c$</td>
<td>Exponent in reservoir storage-elevation function ($S = ah^c$)</td>
</tr>
<tr>
<td>$D$</td>
<td>Velocity-head coefficient $[D = 1.05(Q/B_0)^2/2g = H^2 \Delta k]$</td>
</tr>
<tr>
<td>$g$</td>
<td>Acceleration of gravity</td>
</tr>
<tr>
<td>$h$</td>
<td>Height of steep negative wave without tailwater submergence effect</td>
</tr>
<tr>
<td>$h'$</td>
<td>Height of steep negative wave as affected by tailwater submergence</td>
</tr>
<tr>
<td>$h_d$</td>
<td>Tailwater water-surface elevation above bottom of breach</td>
</tr>
<tr>
<td>$h_m$</td>
<td>Average depth of water in breach at time of breaching</td>
</tr>
<tr>
<td>$h_o$</td>
<td>Depth of reservoir above bottom of breach at time of breaching</td>
</tr>
<tr>
<td>$H$</td>
<td>Depth of reservoir at dam</td>
</tr>
<tr>
<td>$H_c$</td>
<td>Elevation of bottom of breach above bottom of reservoir at dam</td>
</tr>
<tr>
<td>$H_d$</td>
<td>Tailwater water-surface elevation above bottom of reservoir at dam</td>
</tr>
<tr>
<td>$H_o$</td>
<td>Depth of reservoir at dam at time of breaching</td>
</tr>
<tr>
<td>$k$</td>
<td>Energy head on the breach</td>
</tr>
<tr>
<td>$\Delta k$</td>
<td>Velocity head on the breach</td>
</tr>
</tbody>
</table>
L  Length of reservoir at time of breaching
m  Dimensionless outflow coefficient (m = 0.545 \frac{B}{B_o})
N  Term in reservoir-routing working equation (N = \frac{S}{\Delta t} + \frac{Q}{2})
p  Dimensionless ratio of height of steep negative wave and depth of reservoir at dam at time of breaching, without tailwater submergence effect (p = \frac{h}{H_o})
p'  Dimensionless ratio of height of steep negative wave and depth of reservoir at dam at time of breaching, as affected by tailwater submergence (p' = \frac{h'}{H_o})
P_n  Discharge ordinate of total fictitious inflow hydrograph (P_n = P_o + P_w)
P_o  Constant rate of inflow into reservoir
P_w  Discharge component of fictitious inflow hydrograph resulting from passage of steep negative wave
Q  Outflow discharge
Q_a  Discharge of approach to the breach
Q_{max}  Peak outflow discharge, first approximation
Q_o  Peak outflow discharge, second approximation
Q'_{o}  Peak outflow discharge, third approximation
Q_t  Total discharge ordinate of small-breach outflow hydrograph
R  Storage factor \left[ S = S_o R^2 \left( 3 - R \right) / 2 \right]
s  Dimensionless ratio of depth of reservoir above bottom of breach and total depth of reservoir at dam at time of breaching (s = \frac{h_o}{H_o})
S  Total reservoir storage at depth H
S_e  Effective reservoir storage above bottom of breach
\( S_0 \)  Total reservoir storage at time of breaching
\( t \)  Time after breaching
\( \Delta t \)  Time interval
\( t_k \)  Quotient of effective reservoir storage and peak outflow discharge, with the dimension of time \( (t_k = S_e/Q_{\text{max}}) \)
\( w \)  Dimensionless ratio of velocity of reservoir inflow \( (P_0/B_0H_0) \) to celerity of wave \( [w = P_0/B_0H_0(gH_0)^{1/2}] \)
\( x \)  Dimensionless ratio of distance above dam and length of reservoir \( (x=X/L) \)
\( X \)  Distance above dam
### Table 2

**ENGLISH-METRIC UNIT CONVERSION RATIOS**

#### LENGTH

<table>
<thead>
<tr>
<th>ENGLISH</th>
<th>METRIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.54 cm</td>
<td>1.000 in</td>
</tr>
<tr>
<td>3.28 ft</td>
<td>1.01 m</td>
</tr>
<tr>
<td>1.61 km</td>
<td>0.999 mi</td>
</tr>
<tr>
<td>100 m</td>
<td>0.328 ft</td>
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#### AREA

<table>
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<tr>
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</tr>
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<tbody>
<tr>
<td>2.59 km²</td>
<td>2.47 ac.</td>
</tr>
<tr>
<td>259 hectares</td>
<td>1.01 hectometer</td>
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<tr>
<td>2.47 acres</td>
<td>4047 m²</td>
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#### VOLUME

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<tbody>
<tr>
<td>35.31 ft³</td>
<td>1.01 cfs</td>
</tr>
<tr>
<td>43,560 ft³</td>
<td>0.505 cfs/24 hrs</td>
</tr>
<tr>
<td>1,000,000,000 m³</td>
<td>1.01 cfs</td>
</tr>
<tr>
<td>1235.5 m³</td>
<td>28.32 liters</td>
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#### DISCHARGE

<table>
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<tbody>
<tr>
<td>35.31 cfs</td>
<td>1.01 ft³/sec</td>
</tr>
<tr>
<td>0.505 cfs/24 hrs</td>
<td>1.01 ac. ft.</td>
</tr>
<tr>
<td>1.01 cfs</td>
<td>1.01 ac. in/hr</td>
</tr>
</tbody>
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CROSS SECTIONS OF ACTUAL AND IDEALIZED BREACH AND RESERVOIR AT DAM

PROFILE OF WATER SURFACE WITH NEGATIVE WAVE AND TAILWATER SUBMERGENCE

DEFINITION SKETCHES

BREACH AND RESERVOIR
EXAMPLE

AVERAGE DEPTH OF WATER IN BREACH AT TIME OF BREACHING, \( h_m = 50 \) FEET. WIDTH OF BREACH AT ELEVATION \( h_0 \), \( B_{\text{max}} = 80 \) FEET.

\[
Q_{\text{max}} = 3.09 \times B_{\text{max}}^{1.5} = 3.09 \times (80)^{1.5} \\
Q_{\text{max}} = 87,000 \text{ cfs}
\]

OTHER EQUATIONS:

\[
B = Q_{\text{max}} / 3.09 h_0^{1.5} \\
k = (Q_0 / 3.09 B)^{0.66}
\]
EXAMPLE

AVERAGE DEPTH OF WATER IN BREACH AT TIME OF BREACHING, $h_m=40$ METERS. WIDTH OF BREACH AT ELEVATION $h_0$, $B_{max}=60$ METERS.

$Q_{max}=1.71 \cdot B_{max} \cdot h_m^{1.5} = 1.71 \cdot (60) \cdot (40)^{1.5}$

$Q_{max}=26,000 \text{ m}^3/\text{sec}$

OTHER EQUATIONS:

$B=Q_{max}/1.71 \cdot h_0^{1.5}$

$k=(Q_0/1.71 \cdot B)^{0.66}$

PEAK DISCHARGE THRU A RECTANGULAR BREACH, METRIC UNITS

PLATE 2b
EXAMPLE

DEPTH OF RESERVOIR AT TIME OF BREACHING, $H_0 = 50$ FEET. WIDTH OF IDEALIZED RESERVOIR AT THE DAM, $B_0 = 70$ FEET. $B_0 H_0 (g H_0)^{0.5} = (70)(50)[(32)(50)]^{0.5} = 140,000.

OPPOSITE $H_0 = 50$, READ $(g H_0)^{0.5} = [(32)(50)]^{0.5} = 40.0$

NOMOGRAPHS FOR

THE COMPUTATION OF $(g H_0)^{0.5}$ AND $B_0 H_0 (g H_0)^{0.5}$

ENGLISH UNITS
Ho = 60 Meters. Width of idealized reservoir at the dam, B₀=80 Meters. 
B₀H₀(gH₀)₀·₅ = (80)(60)((9.8)(60))₀·₅ = 116,000.

Opposite H₀=60, read (gH₀)₀·₅ = [(9.8)(60)]₀·₅ = 24.3

**Example**

Depth of reservoir at time of breaching, Ho = 60 Meters. Width of idealized reservoir at the dam, B₀=80 Meters. 
B₀H₀(gH₀)₀·₅ = (80)(60)((9.8)(60))₀·₅ = 116,000.

Opposite H₀=60, read (gH₀)₀·₅ = [(9.8)(60)]₀·₅ = 24.3

**NOMOGRAPH FOR THE COMPUTATION OF (gH₀)₀·₅ AND B₀H₀(gH₀)₀·₅**

**METRIC UNITS**
VALUES OF $p$ CORRESPONDING TO $w, s, m$

$w = 0$
VALUES OF $p$ CORRESPONDING TO $w, s, m$

$w = 0.05$
VALUES OF p CORRESPONDING TO 

w,s,m

w=0.10
VALUES OF $p$ CORRESPONDING TO $w, s, m$

$w = 0.15$
VALUES OF $p$
CORRESPONDING TO $w, s, m$

$w=0.20$
VALUES OF $p$ CORRESPONDING TO $w, s, m$

$w = 0.25$
VALUES OF $p$ CORRESPONDING TO $w,s,m$

$w=0.35$
VALUES OF $p$ CORRESPONDING TO 
$w, s, m$

$w = 0.40$
VALUES OF $p$
CORRESPONDING TO $w,s,m$

$w=0.45$
VALUES OF $p$
CORRESPONDING TO
$w, s, m$

$w = 0.50$
VALUES OF

\[ f(p,w) = p[(1-p/2)^{0.5} - w] \]
USE OF GRAPH WHEN \(Q/B_0\) LIES BETWEEN 100 AND 1,000:
Determine from graph the value of \(D\) corresponding to \(Q/10B_0\); multiply by 100.

USE OF GRAPH WHEN \(Q/B_0\) LIES BETWEEN 1 AND 10;
Determine from graph the value of \(D\) corresponding to \(10Q/B_0\); divide by 100.

\[D = 0.0163 (Q/B_0)^2\] ENGLISH UNITS
\[D = 0.0536 (Q/B_0)^2\] METRIC UNITS
VALUES OF STORAGE FACTOR R
$H_C/H_0$ vs $C$ graph with a curve indicating a decrease as $C$ increases. The graph has a grid and is labeled 'STORAGE CURVE EXONENTS.'
DIMENSIONLESS OUTFLOW HYDROGRAPHS
SMALL RECTANGULAR BREACH
APPRECIABLE INFLOW
$c=1.00 (k=1/2)$
DIMENSIONLESS
OUTFLOW HYDROGRAPHS
SMALL RECTANGULAR
BREACH
APPRECIABLE INFLOW
\[ c = 1.12 \left( k = \frac{2}{3} \right) \]
DIMENSIONLESS OUTFLOW HYDROGRAPHS
SMALL RECTANGULAR BREACH
APPRECIABLE INFLOW
c=1.50(k=1)
DIMENSIONLESS OUTFLOW HYDROGRAPHS
SMALL RECTANGULAR BREACH
APPRECIABLE INFLOW
c=1.88(k=6/5)
VALUES OF
\[ f(x,p,w) = x(x-p/2)^{0.5} - w/x \]

\[ w = 0 \]
VALUES OF $f(x,p,w)$:

$$f(x,p,w) = x(x - p/2)^{0.5} - w/x$$

When $w = 0.05$
VALUES OF

\[ f(x,p,w) = x(x-p/2)^{0.5} - w/x \]

\[ w = 0.10 \]
VALUES OF

\[ f(x,p,w) = x(x-p/2)^{0.5} - w/x \]

\[ w = 0.15 \]
VALUES OF

\[ f(x, p, w) = x(x-p/2)^{0.5} - w/x \]

\[ w = 0.20 \]
VALUES OF $f(x,p,w) = x(x-p/2)^{0.5} - w/x$

$w = 0.25$
VALUES OF
\[ f(x,p,w) = x(x-p/2)^{0.5} - w/x \]

\[ w = 0.30 \]
VALUES OF

\[ f(x,p,w) = x(x-p/2)^{0.5} \cdot w/x \]

\[ w = 0.35 \]
VALUES OF

\[ f(x,p,w) = x(x-p/2)^{0.5} - w/x \]

\[ w = 0.40 \]
VALUES OF

\[ f(x, p, w) = x(x - p/2)^{0.5} - w/x \]

\[ w = 0.45 \]
VALUES OF

\[ f(x,p,w) = x(x-p/2)^{0.5} - w/x \]

\[ w = 0.50 \]
VALUES OF
\[ F(x,p,w) = \frac{t(gHo)^{0.5}}{L} \]
\[ w = 0 \]
VALUES OF $F(x,p,w)$

$$F(x,p,w) = (gH)^{0.5}/L$$

$w=0.05$
VALUES OF

\[ F(x, p, w) = \frac{t(gh_0)^{0.5}}{L} \]

\[ w = 0.15 \]
VALUES OF

$F(x, p, w) = \frac{t(gHo)^{0.5}}{L}$

$w = 0.20$
VALUES OF

\[ F(x,p,w) = \frac{t(gHo)^{0.5}}{L} \]

\[ w = 0.25 \]
VALUES OF

\[ F(x,p,w) = t(gH_0)^{0.5}/L \]

\( w = 0.30 \)

PLATE 13g
VALUES OF
\[ F(x,p,w) = t(gHo)^0.5/L \]
\[ w = 0.35 \]
VALUES OF

\[ F(x,p,w) = t(g Ho)^{0.5}/L \]

\[ w = 0.40 \]
VALUES OF

\[ F(x,p,w) \quad t(gH_0)^{0.5}/L \]

\[ w=0.45 \]
VALUES OF

$$F(x,p,w) = t(gHo)^{0.5}/L$$

$$w = 0.50$$
PERFORM STEPS 1-13

IF \( H_d \) GREATER THAN \( H_s \) ?

YES → PERFORM STEP 14

IF \( H_d \) GREATER THAN 0.4 k ?

YES → PERFORM STEPS 15-18

NO → PERFORM STEPS 19-20

IF \( Q_d \) LESS THAN 90% \( Q_{max} \) ?

YES → PERFORM STEPS 31-40

NO → PERFORM STEPS 19

IF \( Q_d \) LESS THAN 90% \( Q_{max} \) ?

YES → PERFORM STEPS 31-40

NO → PERFORM STEPS 31-40

*SMALL-BREACH PROCEDURE

PERFORM STEPS 22-25

IF \( P_d \) LESS THAN 10% \( Q_{max} \) ?

YES → PERFORM STEPS 26-27

NO → PERFORM STEPS 28-30

PERFORM STEPS 41-52

PERFORM STEPS OF SMALL-BREACH PROCEDURE*

PERFORM STEPS IN DETERMINATION OF OUTFLOW HYDROGRAPH
EXAMPLES 1 & 2
CROSS SECTIONS OF BREACH AND RESERVOIR AT DAM

Plate 15
EXAMPLES 1, 3, 4
TAILWATER RATING CURVE
EXAMPLE 1
FICTITIOUS INFLOW HYDROGRAPH
EXAMPLE 1

RELATIONSHIP BETWEEN BREACH DISCHARGE AND RESERVOIR WATER - SURFACE ELEVATION

DISCHARGE $-10^3$ m$^3$/sec
EXAMPLE 1
IDEALIZED RESERVOIR
STORAGE CURVE

H (meters)

STORAGE \(-10^9 \text{ m}^3\)
EXAMPLE 1

RESERVOIR—ROUTING
WORKING CURVES
DISCHARGE—
$10^3 \text{m}^3/\text{sec}$

TIME AFTER BREACHING—(seconds)

EXAMPLE 1

BREACH
OUTFLOW
HYDROGRAPH
EXAMPLE 2
TAILWATER RATING CURVE

DISCHARGE—$10^3$ m$^3$/sec

$H_d$—ELEVATION IN METERS ABOVE BOTTOM OF RESERVOIR AT DAM
EXAMPLE 2
BREACH DISCHARGE RATING WITH ZERO SUBMERGENCE EFFECT
EXAMPLE 2

RELATIONSHIP BETWEEN BREACH DISCHARGE AND VELOCITY HEAD
EXAMPLE 2
RELATIONSHIP BETWEEN DISCHARGE OF APPROACH AND TRIAL SUBMERGENCE RATIOS
EXAMPLE 2
AVERAGE SUBMERGED BREACH DISCHARGE RATING CURVE
EXAMPLE 2
FICTITIOUS INFLOW HYDROGRAPH
EXAMPLE 2
RELATIONSHIP BETWEEN
SUBMERGED-BREACH
DISCHARGE
AND RESERVOIR
WATER SURFACE
ELEVATION
EXAMPLE 2

IDEALIZED RESERVOIR STORAGE CURVE

S - 10^6 m^3

H - (meters)
EXAMPLE 2
RESERVOIR ROUTING WORKING CURVE
\[ \Delta t_1 = 200 \text{ sec} \]
\( N_2 = \frac{S}{\Delta t_2} + \frac{Q}{2 \times 10^3} \)

**DISCHARGE \(-10^3 m^3/sec\)**

**EXAMPLE 2**

**RESERVOIR ROUTING WORKING CURVE**

\( \Delta t_2 = 1,000 \text{ sec} \)
EXAMPLE 2

BREACH OUTFLOW HYDROGRAPH
EXAMPLES 3 & 4
CROSS SECTIONS OF BREACH AND RESERVOIR AT DAM
TIME AFTER BREACHING—(1,000 seconds)

EXITAPE 3

BREACH
OUTFLOW
HYDROGRAPH
TIME AFTER BREACHING—(1,000 seconds)
APPENDIX A.  A SIMPLIFIED PROCEDURE
FOR ESTIMATING THE OUTFLOW HYDROGRAPH FROM A LARGE BREACH

A-1.  General

This appendix presents a simplified procedure for estimating the outflow hydrograph from a large breach. This procedure is based on a set of curves and equations developed in Reference 7, which were obtained by assigning definite values to certain reservoir and channel characteristics, such as bottom slope and roughness, and then computing the breach and tailwater rating curves, the reservoir profile, the effect of tailwater submergence, and finally the breach outflow hydrograph in dimensionless form. Since the values used are not generally applicable to all dams and reservoirs, this method must be considered very approximate. With two exceptions, the symbols used in the procedure are the same as in the main body of the guide and are defined in Table 1; the peak discharge through the breach is computed using a coefficient C and is designated Qest. An example illustrating the application of this procedure is presented below in paragraph A-4. The basic data used in this example are the same as those of Example 2, Chapter 4, enabling comparison of the two solutions.

A-2.  Data assumed to be known

Item

1. \( h_0 \) Depth of reservoir above bottom of breach at time of breaching
2. Cross section of breach
3. \( H_0 \) Depth of reservoir at dam at time of breaching
4. \( S_o \) Total reservoir storage at time of breaching
5. \( L \) Length of reservoir at time of breaching
6. System of measurement (English or metric) to be used in determination

A-3.  Steps in the determination of the estimated outflow hydrograph

a. Conversion of units of measurement

Step  Solution

1  If necessary, convert items 1-5 of the data assumed to be known to the units of measurement to be used in the determination of the hydrograph (item 6 of known data).
b. Idealization of breach

2 On the breach cross section (item 2, known data) measure B_max, the width of the breach at elevation h_0 (item 1, known data). Compute A_max, the area of the breach below elevation h_0. Divide A_max by B_max to obtain h_m, the average depth of water in the breach at the time of breaching.

3 Enter the nomograph on Plate 2a or b (corresponding to the system or measurement used) with the values of h_m and B_max obtained in step 2, to determine Q_max, the first approximation of the peak discharge.

4 Enter the nomograph used in step 3 with the values of Q_max (step 3) and h_0 (item 1 of known data) to obtain B, the width of the idealized breach.

c. Idealization of reservoir

5 Using items 3, 4, and 5 of known data, compute B_0, the width of the idealized reservoir at the dam, by the formula B_0=3S_0/LH_0.

d. Computation of the estimated peak discharge

6 (a) Compute the ratio B/B_0. (B, B_0: steps 4 and 5)

(b) Enter Plate 35 to obtain the discharge coefficient C corresponding to B/B_0. If B/B_0 is less than 0.088, use C=1.00.

(c) Compute Q_est = CQ_max (Q_max: step 3.) Q_est is the estimated peak discharge.

e. Computation of the estimated outflow hydrograph

7 Compute the effective reservoir storage S_e above the bottom of the breach as follows:

(a) Compute H_c = H_0 - h_0 (H_0, h_0: items 3 and 1 of known data). H_c is the elevation of the bottom of the breach above the bottom of the reservoir at the dam. Also compute H_c/H_0.

(b) Determine from Plate 8 the storage factor R corresponding to H_c/H_0.

(c) Compute S_e = S_0(1-R). (S_0: Item 4 of known data)

8 Compute t_k = S_e/Q_est. (S_e: step 7(c); Q_est: step 5(c))

9 Compute the estimated outflow hydrograph as follows:

(a) Enter Plate 36 with the value of the ratio B/B_0 determined in step 6(a) and tabulate the values of t/t_k for that ratio corresponding to the series of values of Q/Q_est shown on the plate.

(b) Multiply each value of t/t_k by t_k (step 8) and each value of Q/Q_est by Q_est (step 6(c)) to obtain t and Q, respectively.
(c) On graph paper plot corresponding values of Q and t, and draw a smooth curve through the plotted points. This is the estimated breach outflow hydrograph.

To check approximately the preceding computations, compute the volume of the breach outflow hydrograph (step 2(c)). This should approximately equal the effective reservoir storage $S_e$ (step 7(c)).
### A-4. Example

**Item**

1. \( h_0 = 75 \) m
2. See Plate 15, Cross Section of Breach.
3. \( H_0 = 100 \) m
4. \( S_0 = 1,580 \times 10^6 \) m³
5. \( L = 50,000 \) m
6. Metric system

**b. Determination of estimated breach outflow hydrograph**

<table>
<thead>
<tr>
<th>Step</th>
<th>Solution</th>
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<tbody>
<tr>
<td>1</td>
<td>Conversion of units of measurement unnecessary</td>
</tr>
<tr>
<td>2</td>
<td>( B_{max} = 650 ) m; ( A_{max} = 47,100 ) m²; ( h_m = 47,100/650 = 72.5 ) m</td>
</tr>
<tr>
<td>3</td>
<td>( Q_{max} = 690,000 ) m³/sec (Enter nomograph with ( B_{max} = 65 ) m; multiply value on ( Q_{max} ) scale by 10.)</td>
</tr>
<tr>
<td>4</td>
<td>( B = 615 ) m.</td>
</tr>
<tr>
<td>5</td>
<td>( B_0 = 3 (1,580 \times 10^6) / (50,000 \times 100) = 950 ) m</td>
</tr>
</tbody>
</table>
| 6    | (a) \( B/B_0 = 615/950 = 0.65 \)  
        (b) \( C = 0.61 \)  
        (c) \( Q_{est} = 0.61 \times 690,000 = 420,000 \) m³/sec |
| 7    | (a) \( H_e = 100 - 75 = 25 \) m; \( R_e/H_e = 25/100 = 0.25 \)  
        (b) \( R = 0.086 \)  
        (c) \( S_e = 1,580 \times 10^6 \times 0.914 = 1,444 \times 10^6 \) m³ |
| 8    | \( t_k = (1,444 \times 10^6) / (420 \times 10^3) = 3,440 \) sec |

<table>
<thead>
<tr>
<th>9</th>
<th>( \frac{Q}{Q_{est}} )</th>
<th>( Q )</th>
<th>( t/t_k )</th>
<th>( \xi )</th>
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</thead>
<tbody>
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<td>1.00</td>
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<tr>
<td>0.10</td>
<td>42,000</td>
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(c) See Plate 37. This is the required solution of the estimated breach outflow hydrograph.

\( \sum Q = 1,150 \times 10^6 \) m³ in first 10,000 sec. This is approximately equal to \( S_e (1,444 \times 10^6 \) m³), taking into consideration the volume of flow ignored after \( t = 10,000 \) sec.
VALUES OF DISCHARGE COEFFICIENT C CORRESPONDING TO RATIO B/BO
DIMENSIONLESS ESTIMATED OUTFLOW HYDROGRAPHS LARGE BREACHES
ESTIMATED BREACH OUTFLOW HYDROGRAPH EXAMPLE - APPENDIX A
Distribution List
for
EIG 4.0 - Computation of Outflow From Breached Dams

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<tr>
<td>Colorado State University, Dept. of Civil Engineering, ATTN: Dr. Yevdjevich</td>
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