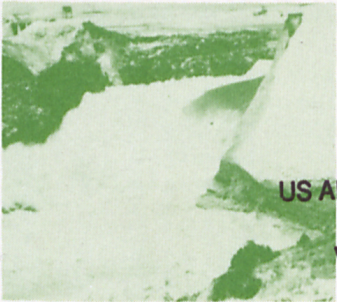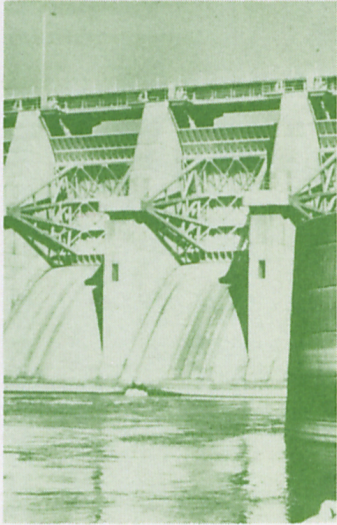# MILITARY HYDROLOGY

Report 20
RESERVOIR OUTFLOW (RESOUT) MODEL

by

Ralph A. Wurbs, Stuart T. Purvis

Texas A&M Research Foundation
College Station, Texas   77843

April 1991

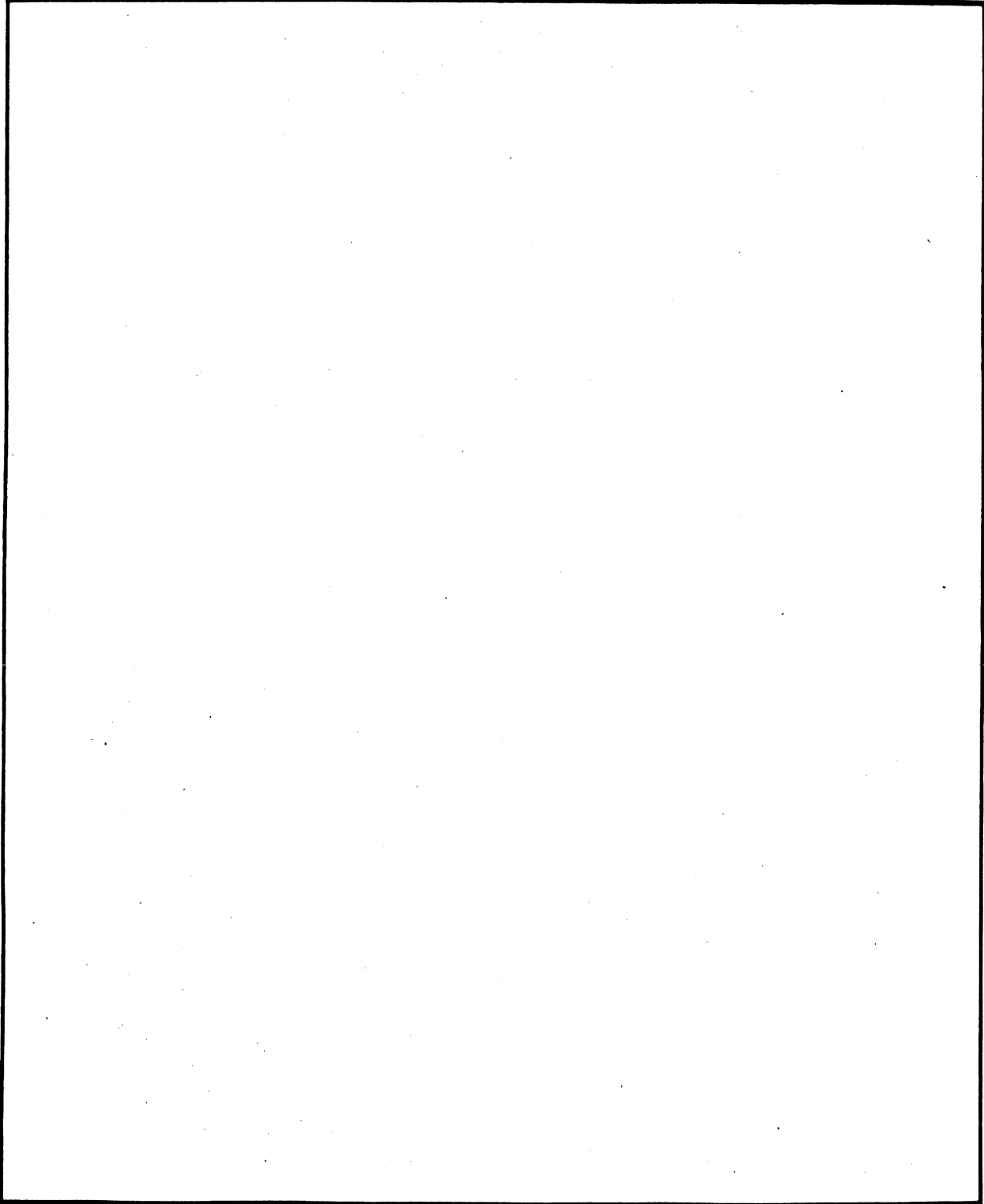Report 20 of a Series

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This report documents the development of the Reservoir Outflow (RESOUT) Model. The various types of structures that are used for discharging water at a dam are identified, and the basic hydraulic equations are presented. These computational procedures are then presented in a computer code written for an MS-DOS microcomputer. Input instructions and example applications are also included.

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PREFACE

The work documented in this report was conducted for the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES) under a contract between the Texas A & M Research Foundation and WES entitled "Development of a Reservoir Outflow Hydrograph Microcomputer Model," Contract No. DACA39-87-M-0674. The work was sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), under Department of the Army Project No. 4A762719AT40, Task Area BO, Work Unit 052. LTC T. Scott was the HQUSACE Technical Monitor.

The study was conducted and the report prepared by Dr. Ralph A. Wurbs, Department of Civil Engineering, Texas A&M University (TAMU), College Station, TX, and Mr. Stuart T. Purvis, also of TAMU. The report was edited by Ms. Janean Shirley of the WES Information Technology Laboratory.

The contract was monitored at WES by Messrs. Mark R. Jourdan and John G. Collins, Environmental Constraints Group (ECG), Environmental Systems Division (ESD), EL, under the general supervision of Mr. Malcolm Keown, Chief, ECG; Dr. Victor E. Lagarde, Chief, ESD; and Dr. John Harrison, Chief, EL. Technical review was provided by Messrs. Jourdan and Collins, and by Mr. Bobby J. Brown, Hydraulics Laboratory, WES.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENTS

Non-SI units of measurement used in this report can be converted to
SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres

MILITARY HYDROLOGY

RESERVOIR OUTFLOW (RESOUT) MODEL

PART I: INTRODUCTION

Background

1. Under the Meteorological/Environmental Plan for Action, Phase I,
approved for implementation on 26 January 1983, the US Army Corps of Engineers
(USACE) has been tasked to implement a research, development, testing, and
evaluation program that will: (a) provide the Army with environmental effects
information needed to operate in a realistic battlefield environment, and (b)
provide the Army with the capability for near-real-time environmental effects
assessment on military materiel and operations in combat. In response to this
tasking, the Directorate for Research and Development, USACE, initiated the
AirLand Battlefield Environment (ALBE) Thrust program. This program will
develop the technologies to provide the field Army with the operational capa-
bility to perform and exploit battlefield effects assessments for tactical
advantage.

2. Military hydrology, one facet of the ALBE Thrust, is a specialized
field of study that deals with the effects of surface and sub-surface water on
planning and conducting military operations. In 1977, Headquarters, US Army
Corps of Engineers (HQUSACE), approved a military hydrology research program.
Management responsibility was subsequently assigned to the Environmental Lab-
oratory, US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS.

3. The objective of military hydrology research is to develop an
improved hydrologic capability for the Armed Forces with emphasis on applica-
tions in the tactical environment. To meet this overall objective, research
is being conducted in four areas: (a) weather-hydrology interactions;
(b) state of the ground; (c) streamflow; and (d) water supply.

4. This report contributes to the streamflow modeling area. Streamflow
modeling is oriented toward the development of procedures for rapidly fore-
casting streamflow parameters including discharge, velocity, depth, width, and
flooded area from natural and man-induced hydrologic events. Specific work
efforts include: (a) the development of simple and objective streamflow

forecasting procedures suitable for Army Terrain Team use; (b) the adaptation of procedures to automatic data processing equipment available to Terrain Teams; (c) the development of procedures for accessing and processing information included in digital terrain data bases; and (d) the development of streamflow analysis and display concepts.

Purpose and Scope

5. A major objective of the USACE military hydrology research is to provide the Armed Forces with improved capabilities for forecasting the downstream flood flow impacts resulting from controlled or uncontrolled (dambreach) releases from dams, levees, and dikes. The microcomputer program and accompanying material presented in this report focus specifically on improving military capabilities for predicting reservoir discharge rates.

6. A package of procedures is presented for computing outlet structure rating curves and outflow hydrographs for various structure configurations. The computations consist of: (a) developing a relationship between water surface elevation and discharge through the outlet structures and/or breach; and, (b) routing a hydrograph through the reservoir. The computational procedures are coded for an IBM PC-compatible microcomputer. Applications could involve predicting reservoir outflows for given conditions; determining outlet structure gate openings or breach size required to achieve specified outflows; or analyzing reservoir drawdowns.

Military Significance of Dams and Reservoirs

7. Most major rivers throughout the world are regulated by systems of dams and reservoirs. Streamflow conditions are highly dependent upon man's operation of reservoirs as well as nature's provision of precipitation. Dams are necessary to control flooding and utilize the surface water resource for beneficial purposes such as agricultural, municipal, and industrial water supply, hydroelectric power generation, and navigation. Although dams have been constructed for thousands of years, tremendous growth in the number and size of dams has occurred during the past half-century.

8. Dams are potential targets for attacks, including terrorism during peacetime as well as military actions during war. Modern weapons provide the capability to inflict any degree of damage to a dam, ranging from removal of a

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spillway gate to complete destruction of the dam. Loss of the services provided by a dam could, in many cases, seriously diminish industrial productivity and overall support of the war effort. Downstream flooding caused by demolition of high dams on many rivers throughout the world would cause catastrophic damage and loss of life.

9. A potential deterrent to an attack on a strategically located dam is to partially empty the reservoir whenever a significant threat of attack is considered to exist. Drawdown plans could be developed which consider drawdown times for various inflow conditions and release constraints and the impacts on reservoir services.

10. Reservoir gates can be operated or a dam breached to induce flooding during military operations. Under appropriate circumstances, reservoir releases can serve as an offensive weapon to damage and disrupt activities in the downstream flood plain. The obstacle effect of induced flooding can also significantly strengthen defensive operations. Reservoirs can be effective in the rapid creation of barriers under expedient conditions. River-crossing operations in the combat zone may be delayed or prevented. The presence of a dam in a headwaters area under the control of the opposing force may necessitate the assembly and construction of river-crossing equipment capable of withstanding a major flood wave or series of flood waves, thereby acting as a deterrent to the operation. The obstacle effects of induced flooding include: (a) increasing velocities and stages to impede river-crossing operations; (b) destruction of bridges and other facilities; and (c) inundation of flood plain lands to adversely impact trafficability.

11. The reservoir itself may provide an obstacle to combat operations upstream of the dam. Situations could occur in which trade-offs exist between using a limited supply of water to maintain high water levels above the dam versus downstream-induced flooding.

12. Combat operations can also be significantly impacted by streamflow conditions resulting from precipitation events. Reservoir operation is an important consideration in forecasting streamflow conditions to be expected from precipitation events. Discharges at a location on a river depend upon releases from upstream reservoirs and runoff from the uncontrolled watershed area below the reservoirs. Backwater effects from downstream reservoirs can also be significant.

PART II: DAMS AND APPURTENANT STRUCTURES

13. A reservoir project includes various water control structures.
Spillways allow flood waters to be discharged while preventing damage to the
dam. Outlet works regulate the release or withdrawal of water for beneficial
purposes. Water may be released to the river below the dam or withdrawn from
the reservoir to be conveyed by pipeline or canal to the location where it is
used. Hydroelectric power plants require appurtenant water control facili-
ties. Navigation locks may be included in a dam to facilitate river trans-
port. The configuration of the dam and appurtenant structures is unique for
each project. However, general characteristics of typical types of structures
are described in the following paragraphs. In-depth treatments of dam and
appurtenant structure design are provided by the US Bureau of Reclamation
(USBR) (1976, 1977a, 1977b); Thomas (1976); Golze (1977); and Davis and
Sorensen (1984).

Dam Types and Configurations

14. Although timber, steel, and stone masonry have been used in con-
structing dams, most dams are earth-fill, rock-fill, or concrete. Dams such
as earth-fill and rock-fill, constructed of natural excavated materials placed
without addition of binding material, are termed embankments. As illustrated
in Figure 1, concrete dams may be categorized as gravity, arch, or buttress.
The stability of a gravity dam is derived primarily from its weight. Arch and
buttress designs reduce the amount of concrete required to withstand the
forces acting on a dam. Arch dams transmit most of the horizontal thrust of
the water stored behind them to the abutments and have thinner cross sections
than gravity dams. A buttress dam consists of a watertight upstream face sup-
ported on the downstream side by a series of intermittent supports termed
buttresses.

15. The 34,798 large dams included in the World Register of Dams
(International Commission on Large Dams 1984) are distributed between types as
follows: earth-fill and rock-fill, 83 percent of the dams; gravity, 11 per-
cent; arch, 4 percent; buttress, 1 percent; and multiple arch, 1 percent. The
353 dams with heights greater than 100 m are distributed as follows: earth-
fill and rock-fill, 41 percent; gravity, 22 percent; arch, 34 percent; but-
tress, 3 percent; and multiple arch, 0.3 percent of the dams. Almost all of

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CROSS SECTION	PLAN VIEW

IMPERMEABLE CORE

a. EMBANKMENT

b. GRAVITY

SIDEWALLS OF CANYON
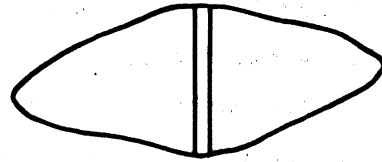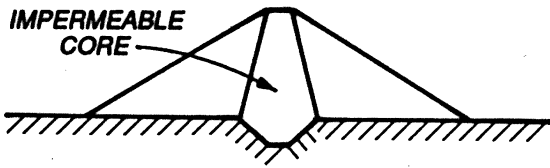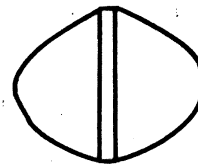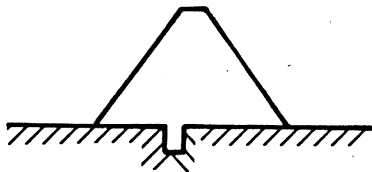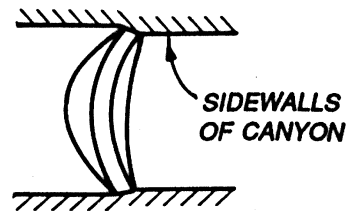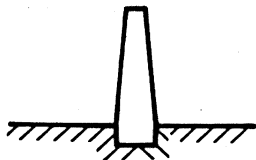
c. ARCH
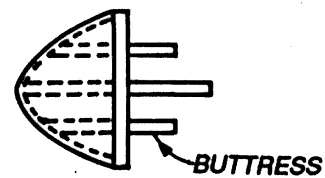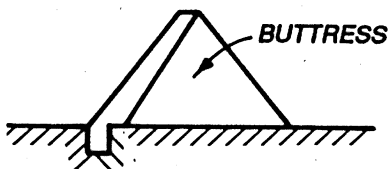
BUTTRESS

BUTTRESS

d. BUTTRESS

Figure 1. General types of dams

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the embankment dams are earth-fill, but some are rock-fill, and some are a combination of earth-fill and rock-fill.

16. Dams are also classified as overflow or non-overflow. Overflow dams are designed for water to flow over their crests. Non-overflow dams are designed to not be overtopped. Overflow dams are limited essentially to concrete. Earth-fill and rock-fill dams are damaged by the erosive action of overflowing water and, consequently, supplemental concrete structures are required to serve as spillways. Most dams are non-overflow.

17. More than one type of dam may be included in a single structure. For example, a concrete section may contain a spillway, with the remainder of the dam being an earthfill embankment. Curved dams may combine both gravity and arch effects to achieve stability.

Spillways

18. A spillway is a safety valve for a dam. Spillways provide the capability to release flood waters or other inflows in excess of normal storage and outlet capacities. The excess water is drawn from the top of the impounded pool and conveyed through a spillway structure and appurtenant channel to the river below the dam. A spillway may be used to allow normal river flows to pass over, through, or around the dam whenever the reservoir is full. Spillways also protect the dam from extreme flood events. Spillway capacity is a critical factor in dam safety, particularly for embankment dams which are likely to be destroyed if overtopped.

19. A spillway may be controlled or uncontrolled. A controlled spillway has gates which can be used to adjust the flow rate. Many reservoirs have a single spillway. Some reservoirs have two or more spillways; a service spillway to convey frequently occurring overflows, and one or more emergency spillways used only during extreme flood events. For some reservoir configurations, water flows through the spillway a large portion of the time, while in other cases, the spillway is designed to be used only for an extreme flood event expected to occur possibly once in several hundred years.

Types of spillways

20. A variety of configurations have been adopted in spillway design. Spillways may be categorized by the path the water takes en route over, through, or around the dam. Typical varieties include overflow, chute, side-channel, and shaft spillways.

21. <u>Overflow spillway.</u> An overflow spillway is a section of dam designed to permit water to flow over the crest. In some cases, the entire length of the dam is an overflow spillway. Overflow spillways are widely used on concrete gravity, arch, and buttress dams. Some earthfill dams have a concrete gravity section designed to serve as an overflow spillway.

22. <u>Chute spillway.</u> A spillway in which water flows from the reservoir to the downstream river through an open channel, located either along a dam abutment or through a saddle some distance from the dam, is called a chute, open channel, or trough type spillway. The chute spillway has been used with earth-fill dams more often than any other type of spillway. The chute may be paved with concrete or asphalt. In some cases in which the spillway is expected to be rarely needed, an unpaved chute through a saddle may be used, realizing that some erosion damage will result whenever the infrequent flood does occur.

23. <u>Side-channel spillway.</u> In a side-channel spillway, water flows over the crest into an open channel running parallel to the crest. The crest is usually a concrete gravity section, but it may consist of pavement laid on an earth embankment or the natural ground surface. This type of spillway is used in narrow canyons where sufficient crest length is not available for overflow or chute spillways.

24. <u>Drop inlet spillway.</u> The drop inlet spillway is also known as a morning-glory or shaft spillway. The water drops through a vertical or inclined shaft to a horizontal conduit or tunnel under, around, or through the dam. Drop inlet spillways are often used where there is inadequate space for other types of spillways. The inlet may consist of either a square-edged or rounded entrance.

<u>Crest shape</u>

25. A spillway control section may be a simple flat, broad-crested weir or, alternatively, may be curved to increase the hydraulic efficiency. The ogee-shaped spillway crest has a curved profile designed to approximate the shape of the lower nappe of a ventilated sheet falling from a sharp-crested weir. At the design head, water flows smoothly over the crest with little resistance from the concrete surface, thus maximizing the discharge. The profile below the upper curve of the ogee spillway is continued tangent along a slope, often with a reverse curve at the bottom of the slope directing the flow onto the apron of a stilling basin. The entrance to drop inlet spillways typically consists of a circular ogee weir.

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Spillway components

26. Spillways typically include an entrance structure or overflow crest, discharge channel or conduit, terminal structure, and approach and outlet channels.

27. In some situations, such as an overflow spillway over a concrete dam, approach and outlet channels may not be required. The water flows directly from the reservoir over the spillway to the river below. However, in many cases, channels are provided to direct the flow to the spillway entrance structure and to convey the flow from the terminal structure back to the river.

28. Water is conveyed from the entrance structure over, around, under, or through the dam to the terminal structure in channels, conduits, or tunnels. As previously discussed, spillways can be classified based on the conveyance method. However, a few spillways have no conveyance structure. For example, the discharge may fall freely through the air from an arch dam crest, or flow may be released directly along an abutment to cascade down the hillside.

29. The difference in elevation between the reservoir water surface and downstream river results in extremely high flow velocities at the spillway exit. Consequently, energy dissipation is usually required to prevent damaging erosion. A principal function of a terminal structure is to dissipate kinetic energy prior to release of the water to the outlet channel or river. Concrete stilling basins are typically provided to facilitate loss of energy in the turbulence of a hydraulic jump. Baffle blocks and end sills increase the efficiency of the energy loss in the basin. Other types of terminal devices include deflector buckets where flow is projected as a free-discharging upturned jet to fall into the stream channel some distance below the end of the spillway. Erosion in the stream bed may be minimized by fanning the jet into a thin sheet by the use of a flaring deflector.

Spillway crest gates

30. An ungated or free-overflow spillway crest automatically regulates the discharge as a function of the elevation of the reservoir water surface, without requiring release decisions by an operator. Additional control of the storage capacity above the spillway crest can be provided by crest gates. The full-discharge capacity of the spillway may be utilized during extreme flood events with water being stored behind closed gates during non-flooding or less severe flooding situations. Many types of spillway crest gates have been

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devised. Several common types are illustrated in Figure 2 and described in the following paragraphs.

31. <u>Lift gates.</u> Rectangular lift gates span horizontally between guide grooves in supporting piers. The support guides may be either vertical or inclined slightly downstream. The gates are raised or lowered by an overhead hoist. Water flows over the spillway crest, under the opened gate. The gates are typically made of steel, but at some dams are timber or concrete.

32. The edges of a lift gate may bear directly on the supporting guides. However, the sliding friction that must be overcome to operate the gate limits the gate size for which this type of installation is practical. Rollers or wheels are often used to reduce the frictional resistance and thereby permit use of a larger gate and/or smaller hoist. Large lift gates are often built in two horizontal sections so that the upper portion may be lifted and removed from the guides before the lower portion is moved. This design reduces the load on the hoisting mechanism and minimizes the headroom required.

33. <u>Tainter gates.</u> The tainter, or radial, gate is probably the most widely used type of crest gate for large installations. Tainter gates are usually constructed of steel or a combination of steel and wood. The cylindrical face of the gate is supported by radial arms attached to trunnions set in the downstream portion of the piers on the spillway crest. The gate pivots around the trunnions as it is opened or closed. Water flows between the bottom of the gate and the spillway crest when the gate is raised. Flexible fabric or rubber stripping is used to form a water seal between the gate and the piers and spillway crest.

34. The gate face is made concentric to the pivot pins so that the entire force of the water passes through the pins. Thus, the moment required to be overcome in raising and lowering the gate is minimized. Counterweights are often used to partially counterbalance the weight of the gate and thus reduce the required capacity of the hoist. The small hoisting effort needed to operate tainter gates makes hand operation practical on small installations. However, gates are typically operated by cables fixed to motor-driven winches set on platforms above the gate.

35. Tainter gates vary in size from 1 m to over 10 m in height and from 2 to 20 m in width. A spillway may contain as many as 20 or more gates, set side by side. Each gate may have its independent hoisting mechanism, or a common unit may be moved from gate to gate.

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HOIST

WATER
SURFACE

TRUNNION

SPILLWAY CREST

a. Tainter gate

HOIST

GATE
GUIDE

ROLLERS

SPILLWAY CREST

b. Lift gate

HOIST

WATER
SURFACE

RACK

c. Rolling gate

WATER
SURFACE

HINGE

HOLLOW
CHAMBER
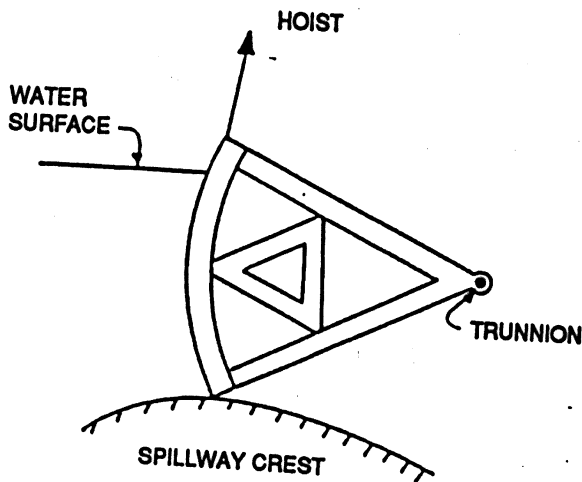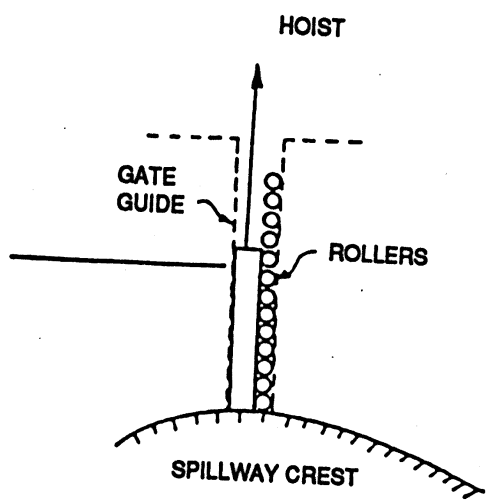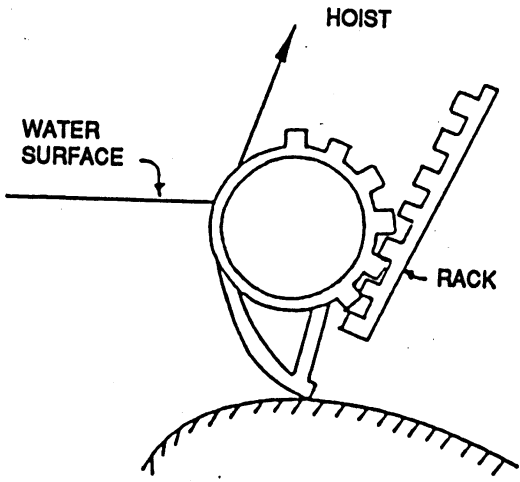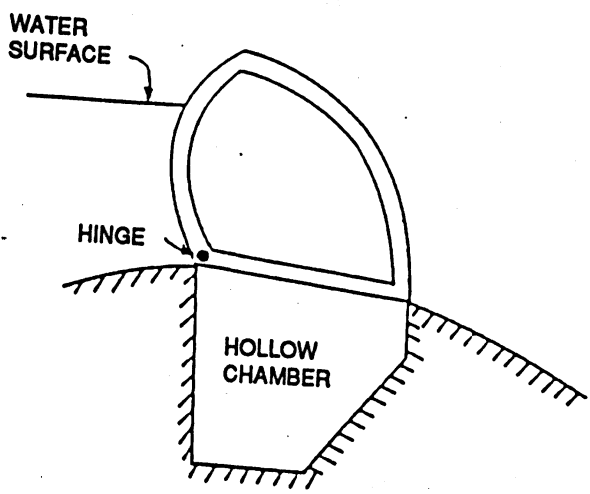
d. Drum gate

Figure 2. Types of spillway crest gates

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36. Due to the relatively small hoisting forces involved, tainter gates are more adaptable than other types of gates to operation by automatic control apparatus. Multiple gates can be arranged to open automatically at successively increasing reservoir levels. Some gates may be opened automatically with the remaining gates on the spillway requiring manual operation.

37. Rolling gates. A rolling, or roller, gate consists of a steel cylinder spanning between the piers. Each pier has an inclined rack which engages gear teeth encircling the ends of the cylinder. The gate is rolled up the rack with a cable and hoist, allowing water to flow beneath the gate. Rolling gates are well adapted to long spans of moderate height.

38. Drum gates. A drum gate consists of a hollow drum which, in the lowered or open position, fits in a recess in the top of the spillway. When water flows over the spillway crest and into the recess, the gate is lifted, completely or at least partially, by the buoyant force.

39. Stop logs. Stop logs are sometimes used as an economical substitute for more elaborate gates where relatively close spacing of piers is not objectionable and gate openings are required only infrequently. Stop logs are horizontal beams or girders set one upon the other to form a bulkhead supported in grooves in piers at each end of the span. Discharge is controlled by installing and removing stop logs. The logs may be raised by hand or with a hoist.

Outlet Works

40. Whereas spillways are provided to handle floods and other inflows surpassing the reservoir storage capacity, an outlet works is used for normal project operations. Outlet works control the storage capacity below the spillway crest elevation. Releases are made to meet municipal, industrial, and agricultural water supply needs, to maintain flows in the river downstream for navigation, pollution abatement, and preservation of aquatic life, and for other beneficial purposes. An outlet works also serves to empty the reservoir to allow inspection, maintenance, and repairs to the dam and other structures. Outlet works may also be used for flood control, to evacuate storage below the spillway crest in anticipation of flood inflows, or to supplement spillway releases during and after a flood event.

41. At some dams, an outlet works has been combined with a service spillway and used in conjunction with a secondary emergency spillway. In this

situation, the usual outlet works design is modified to include an overflow weir which automatically bypasses surplus inflows whenever the reservoir rises above the normal storage level. Extreme flood events exceeding the capacity of the combined service spillway and outlet works are handled by a separate emergency spillway.

42. In many cases, outlet works empty into the river channel below the dam. The water may serve instream purposes and/or be withdrawn from the river at some distance below the dam. In other cases, the outlet works discharges directly into a canal or pipe conveyance system for transport to the location of water use.

Outlet works components

43. An outlet works typically consists of a sluiceway, intake structure, gates or valves, terminal structure, and entrance and exit channels.

44. Sluiceways. A sluiceway is a passageway through, under, or around a dam. Sluiceways for concrete dams generally pass through the dam. Often the outlet conduit is placed through a spillway overflow section, using a common stilling basin to dissipate energy for both spillway and outlet works flows. For embankment dams, the sluiceway is typically placed outside the limits of the embankment fill material. If a conduit is placed through an embankment, collars are normally used to reduce seepage along the outside of the conduit. Sluiceways are typically concrete, though steel or other materials may be used. Tunnels through rock abutments are sometimes constructed without lining. Cross sections may be circular or rectangular. In large concrete dams, multiple smaller conduits are often used instead of a single large conduit.

45. Intake structures. Although the entrance to a sluiceway may be an integral part of the dam or another structure, most outlet works have an intake structure. The primary function of the intake structure is to permit withdrawal of water from the reservoir over a range of pool levels and to protect the conduit from damage or clogging as a result of waves, currents, debris, or ice. Intake structures vary from a simple concrete block supporting the end of a pipe to elaborate concrete intake towers.

46. An intake structure may either be submerged or extended as a tower to some height above the maximum reservoir water surface, depending on its function. A submerged intake consists of a rock-filled crib or concrete block which supports the end of the conduit. Submerged intakes are widely used on small projects because of their low cost.

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47. A tower is required if operating gates are located at the intake or if a platform is needed for installing stop logs or maintaining and cleaning trashracks and fish screens. Intake towers are usually provided with ports at various levels which may aid flow regulation and permit some selection of the quality of water to be withdrawn. A wet intake tower consists of a concrete shell filled with water to the level of the reservoir and has a vertical shaft inside connected to the withdrawal conduit. Gates are normally provided on the inside shaft to regulate flow. With a dry intake tower, the entry ports are connected directly to the sluiceway, without water entering the tower.

48. Intake structures are often provided with trashracks to prevent entrance of debris. Trashrack structures can be found in various designs and configurations. The racks usually consist of steel bars spaced several centimeters apart. Debris accumulations may be removed by hand or by automatic power-driven rack rakes. Sometimes screens are also provided to prevent fish from being carried through the outlet works.

Gates and valves

49. Intake structures usually contain control devices. In some cases, normal flow regulation is achieved by gates or valves at the intake. In other cases, flow is regulated by gates or valves located in the sluiceway some distance downstream of the entrance. However, additional gates are still provided in the intake structure to de-water the conduit for inspections or repairs. A valve in the interior of the sluiceway may be used to regulate flow, with intake gates being used routinely to keep the sluiceway empty during periods of no releases.

50. Entrance gates. Gates at the sluiceway entrance are often used to regulate flow for projects with heads less than roughly 30 m. For higher heads, due to cavitation and vibration problems associated with partly opened gates under high heads, entrance gates are usually used only to de-water the sluiceway for maintenance and repair of the conduit or downstream gates. Small gates on low-head installations are often simple sliding gates operated by hand or motor-powered drives. Slide gates often have bronze bearing surfaces to minimize friction. Rollers are required for high-head installations or for very large gates under low heads.

51. Tractor gates are often used for outlet works under high heads. A tractor gate is rectangular in shape and lifts vertically in grooves. Wedge-shaped roller trains are attached to the back of the gate on either side. As the gate is lowered into the closed position, its downward motion is halted

when its bottom edge comes in contact with the bottom of the gate frame. The roller trains, moving in slots beside the gate, continue their downward movement, and because of their wedge shape, permit the gate to move a small distance downstream. The pressure of the water forces the gate tightly into the gate frame to form a watertight seal. Air ducts are sometimes provided in the sluiceway to reduce cavitation during gate operation. Hoisting equipment is located above the gate.

52. Ports in wet intake towers are typically controlled by gates mounted either inside or outside the shaft. The gates consist of a steel plate and framework which can be raised or lowered to cover the port opening.

53. Bulkheads and stop logs are often provided for de-watering the sluiceway and possibly the intake tower for maintenance and repairs. Bulkhead slots may be provided in the intake structure with the bulkheads being hoisted into place when needed.

54. _Interior gate valves._ At many dams, releases are regulated by valves located in the sluiceway at some distance downstream of the entrance. For sluiceways in gravity dams, the valve operating mechanism is often in a gallery inside the dam. In other cases, the operating mechanism extends to the surface of the dam. For heads under 25 m, flow is often regulated by gate settings. For greater heads, gates are ordinarily used in only the fully open or fully closed position. High-head regulating valves, such as needle and Howell-Bunger valves, allow varying valve settings. Multiple sluices allow discharge rates to be varied by the number of sluices open.

Other Structures

55. Other water control structures associated with dams include water supply intake and diversion structures, hydroelectric power plants, and navigation locks.

Water supply diversions

56. Water for agricultural, municipal, industrial, and other uses may be withdrawn directly from the reservoir or from the river at some distance below the dam. Intake towers with pumps may be located near the dam or in the upper reaches of a reservoir. Water is pumped from the reservoir to be conveyed by pipeline to the location where it is used. In other cases, water released through outlet works is pumped from the river at downstream locations.

57. The term "barrage" is sometimes used to refer to relatively low-head diversion dams often associated with irrigation. The function of a barrage is to raise the river level sufficiently to divert flow into a water supply canal.

Hydroelectric power plants

58. Each hydroelectric power project has its own unique layout and design. The powerhouse may be located at one end of the dam, directly downstream from the dam, or between buttresses in a buttress dam. In some cases, water is conveyed through a penstock to a powerhouse located some distance below the dam. With favorable topography, a high head can be achieved in this manner, even with a low dam. A re-regulating dam is often provided below the hydroelectric plant.

59. A hydroelectric power project typically includes, in some form, a diversion and intake structure, a penstock or conduit to convey the water from the reservoir to the turbines, the turbines and governors, housing for the equipment, transformers, and transmission lines to distribution centers. A forebay or surge tank regulates the head. Trashracks and gates are typically provided in the intake structure. A draft tube delivers the water from the turbines to the tailrace, through which it is returned to the river.

Navigation locks

60. Dams on rivers used for navigation often include locks. A navigation lock is a rectangular box-like structure with gates at either end that allows vessels to move upstream or downstream through a dam. Lockage occurs as follows (assuming a vessel is traveling upstream): (a) the lock chamber is emptied, (b) the downstream gate is opened and the vessel enters the lock, (c) the chamber is filled, with the water lifting the vessel to the level of the reservoir, (d) the upstream gate is opened and the vessel departs. A lock at the Ust-Kamengorsk Dam on the Irtish River in the USSR has a lift of 42 m. The highest lock in the United States is the John Day lock on the Columbia River at 34.5 m (Linsley and Franzini 1979).

PART III: REVIEW OF BASIC HYDRAULIC EQUATIONS

61. Reservoir outlet structures consist of weirs, orifices, conduits, and open channels. Discharges through the structures are determined using fundamental equations of hydraulics, including energy, continuity, head loss, weir, and orifice equations. The equations are covered in standard textbooks and handbooks, such as Brater and King (1976), Davis and Sorensen (1984), Morris and Wiggert (1972), and French (1985), and are reproduced below for ready reference. The application of the basic equations to the specific problem of computing discharges through various types of reservoir control structures is addressed in Part IV.

Continuity Equation

62. The continuity equation expresses the concept of conservation of mass. Fluid is neither lost nor gained. For steady, incompressible flow, the continuity equation may be expressed as follows:

$$Q = V_1 A_1 = V_2 A_2 \tag{1}$$

where

  Q = discharge

  V = average velocity

  A = cross-sectional area

The subscripts refer to the location of the cross section.

63. Flow is classified as steady when the flow characteristics, such as discharge, velocity, and depth, are constant over time. Flow characteristics change over time in unsteady flow. Determining a reservoir outflow hydrograph using storage routing is an unsteady flow problem. The storage form of the continuity equation for unsteady flow is as follows:

$$I - O = dS/dt \tag{2}$$

where

  I = inflow rate

O — outflow rate

dS/dt — change in storage with respect to time

For computational purposes, the equation is written in finite difference form as follows:

$$(I_1 + I_2)/2 - (O_1 + O_2)/2 = (S_2 - S_1)/t \tag{3}$$

where the subscripts 1 and 2 refer to the beginning and end of a computational time interval t.

Energy Equation

64. The principle of conservation of energy may be expressed as follows:

$$Z_1 + p_2/\gamma + V_1^2/2g = Z_2 + p_2/\gamma + V_2^2/2g + h_L \tag{4}$$

where

Z — vertical distance above an arbitrary horizontal datum

p — pressure

γ — unit weight of the fluid

g — gravitational acceleration constant

h_L — head loss

This equation states that the energy at one point in a fluid (subscript 1) is equal to the energy at any downstream location (subscript 2), plus the energy losses occurring between the two locations. The energy is expressed in terms of head, which is energy per unit weight of fluid, with units of ft-lb/lb or N-m/N (ft or m). Total head is the summation of elevation head (Z), pressure head (p/γ), and velocity head $(V^2/2g)$.

Head Loss Equations

65. The Manning and Darcy-Weisbach equations are widely used to esti-mate the head loss (h_L) term in the energy equation. The Manning equation is a general-purpose formula relating discharge or velocity to channel

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characteristics for uniform flow. It is also used to estimate head loss for gradually varied flow. Although associated primarily with open channel flow, the Manning equation can also be applied to pipe flow. The Darcy-Weisbach equation is limited strictly to pipe flow.

Manning equation

66. The Manning equation is as follows:

$$Q = (1.486/n) \, A \, R^{2/3} \, S^{1/2} \quad (English \; units)$$

$$Q = (1/n) \, A \, R_{2/3} S^{1/2} \quad (metric \; units)$$

(5)

where

    n — empirically determined roughness coefficient

    R — hydraulic radius, ft or m

    S — slope of the energy line

The hydraulic radius $R = A/WP$, where WP = the wetted perimeter. The Manning equation was developed for uniform flow, for which the slope of the energy line (S) is equal to the slope of the water surface (hydraulic grade line in pipe flow) and channel bottom. Standard hydraulic references, such as Chow (1959), provide empirical data to aid in estimating the roughness coefficient (n).

67. Since $h_L = SL$, where L is the length of channel or pipe, the Manning equation can be expressed in terms of head loss as follows:

$$h_L = n^2 V^2 L / 2.22 R^{4/3} \quad (English \; units)$$

$$or \qquad h_L = n^2 V^2 L / R^{4/3} \qquad (metric \; units)$$

(6)

In gradually varied flow, V and R are estimated as the average of the values at either end of the reach.

Darcy-Weisbach equation

68. The head loss due to friction in a straight section of pipe may be estimated by the Darcy-Weisbach equation:

$$h_L = f(L/D) (V^2/2g) \qquad\qquad (7)$$

where

      D — pipe diameter

      f — empirical friction factor

The friction factor (f) can be determined as a function of pipe diameter, pipe roughness, and velocity, using the Moody diagram and accompanying tables found in standard hydraulics references such as Davis and Sorensen (1984) and Linsley and Franzini (1979).

Weir Equations

Definition of terms

     69. A weir is a notch of regular form through which water flows. The term is also applied to the structure containing such a notch (Brater and King 1976). The crest of a weir is the edge or surface over which the water flows. A weir with a sharp upstream corner, or edge, such that the water breaks con- tact with the crest is called a sharp-crested weir. A broad-crested weir has a horizontal, or nearly horizontal, crest sufficiently long in the direction of flow so that the nappe will be supported and hydrostatic pressure will be fully developed for at least a short distance. A weir crest may also be rounded. Sharp-crested weirs are typically used as flow-measuring devices. Broad-crested and round-crested weirs are commonly incorporated in hydraulic structures to control the flow of water. Flow measurement is a secondary function in this case. Ogee spillways, discussed later, are designed to approximate flow conditions over a sharp-crested weir. Weirs can also be categorized by the shape of the notch, such as rectangular, triangular, or trapezoidal. If the weir length is less than the width of the approach chan- nel, it is said to have end contractions. A suppressed weir is one with no end contractions. Types of weirs are illustrated in Figure 3.

     70. The sheet of water flowing over a weir is termed a nappe. Free discharge means the nappe discharges into the air. If the tailwater is above the weir crest, the weir is said to be submerged, or drowned.

Basic form of weir equations

     71. Flow over a weir is a complex phenomenon requiring an empirical, rather than a rigorous analytical, solution. Flow patterns vary from one weir
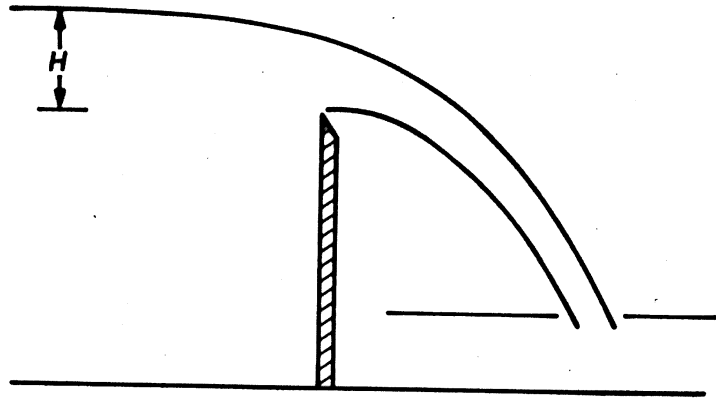
a. **SHARP-CRESTED WEIR**
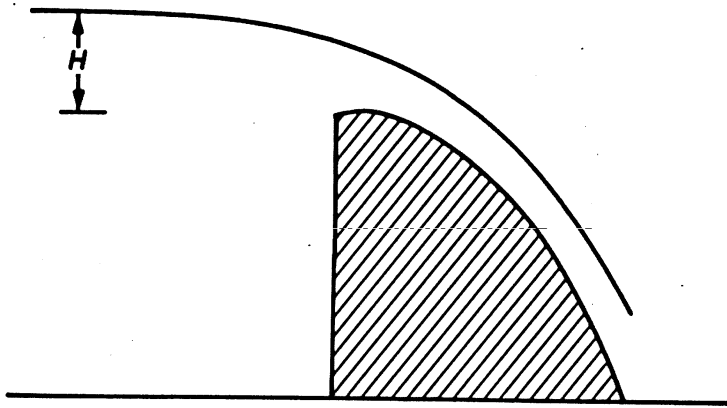
b. **ROUND-CRESTED WEIR**
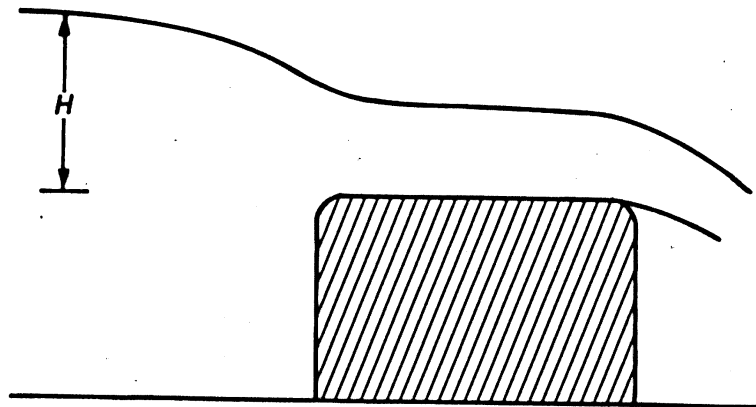
c. **BROAD-CRESTED WEIR**

Figure 3. Types of weirs

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to another. The flow pattern for a given weir varies with discharge. Consequently, the equation for discharge over a weir cannot be derived exactly. Many hydraulics and fluid mechanics books, such as Brater and King (1976) and Daugherty, Franzini, and Finnemore (1985), present approximate derivations. The simplified derivations are based on writing the energy equation between points in the water surface upstream of the weir and in the nappe. The upstream point is at a sufficient distance from the weir so that drawdown effects are negligible. With zero pressure head at the water surface, the equation is expressed as follows.

$$H_a + \alpha_a V_a^2/2g = y_n + \alpha_n Vn2/2g + h_L \tag{8}$$

where

      H — depth above the spillway crest

      a — subscript that denotes selected sections through the approach

      α — kinetic energy correction factor

      y — depth above the spillway crest

      n — subscript that denotes selected sections through the nappe

The equation is solved for V_n.

$$V_n = \left[2g\left(H_a + \alpha_a V_a^2/2g - y_n - h_L\right)\right]^{0.5} \tag{9}$$

Substituting Q — VA, the above equation is rewritten.

$$Q_n = A_n[2g(H_a + \alpha_a V_a^2/2g - y_n - h_L)]^{0.5} \tag{10}$$

72. The terms within the parentheses are all an expression of head or depth. This provides a general form for an equation in which discharge equals a coefficient times cross-sectional area times a head or depth term raised to the 0.5 power. Area also incorporates a head or depth term, which multiplied by the head term in parentheses in the above equation results in a power greater than 0.5.

73. For a rectangular weir, area is depth times weir length. The weir discharge equation is typically expressed in the general form

$$Q = CLH^{1.5} \qquad (11)$$

where C is an empirical coefficient reflecting all variables not included in the L and H terms.

74. For a weir with a triangular-shaped notch, the cross-sectional flow area is $H^2\tan\phi/2$, where ϕ is the notch angle. Thus, the weir discharge equation for a triangular weir is typically expressed in the general form:

$$Q = CH^{2.5} \qquad (12)$$

75. Weir equations are necessarily empirical. Most investigators have used the 1.5 and 2.5 exponents indicated above, with values of C being determined empirically from laboratory or prototype measurements. However, in some cases, the weir equation has been expressed as

$$Q = CH^n \qquad (13)$$

with both C and the exponent n being fitted to empirical data.

76. The head term (H) is often defined as total specific energy above the weir crest elevation, including both flow depth and velocity head. Alternatively, the head may be defined as depth only, with approach velocity being reflected, along with many other variables, in the weir coefficient (C).

Weir coefficients

77. The weir discharge coefficient (C) is a function of a number of factors, including the weir shape and configuration, upstream flow conditions, and downstream submergence effects. Conditions increasing frictional resistance, turbulence, and the resulting energy losses decrease the weir coefficient and corresponding discharge. A round-crested weir will be more hydraulically efficient with a larger coefficient than a broad-crested weir, all other conditions being constant. The sharp-crested weir has the largest possible coefficient.

78. The theoretical maximum value of C for a rectangular broad-crested weir is 3.087, for length (L) and head (H) expressed in feet and discharge (Q) in cubic feet per second, resulting in the following weir equation.

$$Q = 3.087 \, LH^{1.5} \tag{14}$$

The value of 3.087 for C assumes the upstream corner of the weir is rounded to entirely prevent contraction and that flow over the weir goes through critical depth. This is the maximum value of the coefficient that can be obtained for broad-crested weirs under any conditions. Sharp-crested and round-crested weirs have higher coefficients. If L and H are expressed in metres and Q in cubic metres per second, the maximum value for C is 1.705 rather than 3.087.

79. For other than the ideal condition described above, weir discharge coefficients must be determined empirically. Coefficient values are typically estimated based on published data, which have been developed from laboratory and prototype tests. Brater and King (1976) and Bos (1976 and 1985) reference the various laboratory studies which have been conducted and present weir coefficient formulas and data for various types of weirs and flow conditions. Weir coefficients for spillways are discussed later in this report.

Orifice Equations

Definition of terms

80. An orifice is an opening with closed perimeter and of regular form through which water flows. If the opening flows only partially full, the orifice becomes a weir. An orifice with a sharp upstream edge, as illustrated in Figure 4, is called a sharp-edged orifice. An orifice with prolonged sides is called a tube. The depth of water producing discharge is the head. The stream of water which issues from an orifice is termed the jet. Discharge is free or submerged, depending on whether the jet is discharging into air or under water. The jet issuing from a sharp-edged orifice contracts until it reaches the vena contracta. At the vena contracta, the paths of all elements of the jet are parallel and the pressure in the jet can be assumed to be equal to that in the surrounding fluid.

a. SHARP-EDGED ORIFICE   b. TUBE ORIFICE
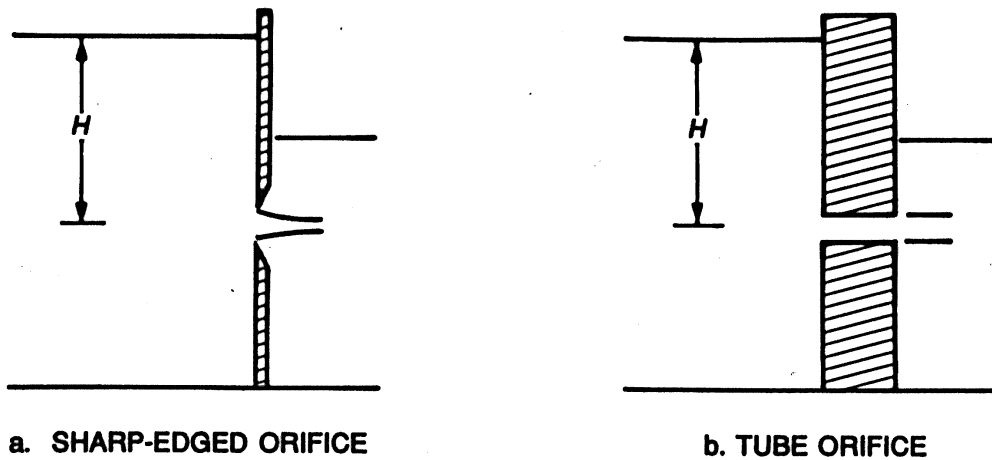
Figure 4. Types of orifices

Basic form of orifice equations

81. The energy equation written from any point upstream of the orifice (subscript 1) to the vena contracta (subscript 2), taking the datum plane through the center of the orifice, is

$$V_1^2/2g + p_1/\gamma = V_2^2/2g = P_2/\gamma = h_L \tag{15}$$

which can be rearranged to

$$V_2 = [2g(p_1/\gamma - p_2/\gamma + V_1^2/2g - h_L)]^{0.5} \tag{16}$$

Since point 2 is located in the vena contracta, the pressure is that of the surrounding fluid. For discharge into the atmosphere, p is zero. Assuming negligible approach velocity, V_1 is zero. Replacing p_1/γ with head (H) and neglecting energy losses, the velocity in the vena contracta is

$$V_2 = (2gH)^{0.5} \tag{17}$$

The discharge is the product of the velocity and the area at the vena contracta. The coefficient of discharge (C) reflects energy losses and the ratio

of the area of the vena contracta to the area of the orifice. Thus, the discharge equation for an orifice can be expressed as

$$Q = CA(2gH)^{0.5} \tag{18}$$

82. When the head is relatively small compared with the size of the orifice, the discharge for a rectangular orifice is given as follows

$$Q = 2/3C(2g)^{0.5} L(H_2^{1.5} - H_1^{1.5}) \tag{19}$$

where

L — orifice width

H_1 — head above the top of the orifice

H_2 — head above the bottom of the orifice

The expression $2/3C(2g)^{0.5}$ is often designated as an overall coefficient.

Orifice coefficients

83. The orifice discharge coefficient (C) depends upon head, design, and shape of the orifice, approach channel flow conditions, and downstream discharge conditions. Coefficient values are typically estimated based on published data, which have been developed from laboratory and prototype experiments. For a sharp-edged circular orifice, $C = Q/(A(2gH)^{0.5})$ has a value of about 0.60 for a wide range of heads. C is dimensionless and thus the same for metric and English units. Brater and King (1976) and Bos (1976) reference the various laboratory studies which have been conducted and present orifice coefficient formulas and data for various types of orifices and flow conditions. Discharge coefficients for outlet works and spillway gate openings are addressed in Part IV.

PART IV: RESERVOIR OUTFLOW COMPUTATIONAL PROCEDURES

84.   The Reservoir Outflow (RESOUT) Model is a generalized computer program for determining discharges from reservoirs. The program consists of a flexible package of procedures, with various options which can be used as needed in a wide range of applications. Applications could involve predicting reservoir outflows for given conditions; determining outlet structure gate openings or breach size required to achieve specified outflows; or analyzing reservoir drawdowns. Part V of this report is a description of the computer program. The computational procedures included in the model are outlined in the present chapter.

85.   Three basic types of computations are involved: (a) developing rating curves, (b) storage routing, and (c) breach simulation. Rating curves can be developed for various types of outlet structures. For certain applications, outlet structure rating curves may be the only output desired. For example, the rating curves may be used to determine gate openings required to achieve specified discharges. In other applications, the computed rating curve may be provided as input to the reservoir routing computations. For given reservoir inflows, storage characteristics, and a given outlet structure rating curve, storages and outflows are computed as a function of time. The breach simulation is a special option which allows an opening in the dam, which grows larger over time, to be incorporated in the reservoir routing. Evaporation losses and target outflows can also be included in the routing.

Introductory Overview of Rating Curves

86.   A rating curve is the relationship between reservoir water surface elevation and discharge through an outlet structure. Discharge is a function of head, or water depth, above the spillway crest or outlet opening. A family of rating curves is required to express the water surface elevation versus discharge relationship as a function of gate opening. Rating, or discharge, curves provide fundamental information for real-time reservoir operation as well as for mathematical modeling studies. Since stage is much easier to measure than discharge, the discharge from a reservoir is determined by applying the measured water surface elevation to the rating curve. For a given measured reservoir level, rating curves are used to select a gate opening or number of sluices to open to achieve a desired release rate.

87. Rating curves are developed as an integral part of the design of a reservoir project and are available for operational purposes after completion of construction. Rating curves for existing structures can also be developed from actual measurements of stage and discharge. However, military situations could result in the need to compute rating curves for existing projects under expedient conditions with limited data.

88. Rating curve computation procedures are based on weir and orifice equations. Uncontrolled spillways are weirs, modeled using weir equations. A dam breach is a weir with time-varying dimensions. Gate openings at gated spillways are orifices. Discharge through an outlet works conduit is also computed using a form of the orifice equation. Methods are incorporated into the weir and orifice computations to reflect approach velocity, submergence, and other conditions. Empirical data are required to estimate values for the coefficients for various types and configurations of structures.

89. Procedures followed by USACE in the hydraulic design of spillways and outlet works, including development of rating curves, are outlined in Engineer Manuals (USACE 1963, 1965), which rely heavily upon hydraulic design criteria prepared for OCE by WES (US Army, Office, Chief of Engineers 1988). USBR provides another authoritative reference on hydraulic design of spillways and outlet works (1977), which includes empirical coefficients and other data needed for developing rating curves for various types of structures. This general topic area is also included in textbooks and handbooks including Chow (1959) and Davis and Sorensen (1984). USACE and USBR use many of the same methods and data. USACE and USBR studies also form the basis for much of the material presented in the hydraulics textbooks and handbooks. Studies accomplished in conjunction with the Boulder Canyon Project (USBR 1948) are an example of early work which significantly contributed to design procedures and empirical data still in use today. The American Society of Civil Engineers (ASCE) developed a comprehensive bibliography (ASCE 1963). Maynord (1985) describes recent investigations at WES on spillway crest shapes and associated discharge coefficients. The procedures outlined below and incorporated in the RESOUT Model are based primarily on USACE references, with some additional methods and data from USBR and other sources.

Rating Curves for Uncontrolled Ogee Spillways

90. The characteristics of flow over a sharp-crested weir were recognized early in the history of hydraulics as the basis for design of round-crested spillways (Chow 1959). The ogee crest profile is designed to conform to the shape of the underside of the nappe of flow over a sharp-crested weir. The ogee shape is commonly used for spillways because it maximizes hydraulic efficiency. The spillway width required for a specified design head and discharge is minimized. Ogee crests are used with overflow, chute, or side-channel spillways, with development of rating curves being essentially the same for the different spillway types.

91. The Corps of Engineers and Bureau of Reclamation have conducted extensive studies on the hydraulics of ogee spillways and have developed standard design methods, including techniques and data for developing rating curves (USACE 1965 and USBR 1977). The data reproduced here are strictly applicable to ogee spillways designed in accordance with standard USACE and USBR criteria. However, these and similar available data are also useful, though somewhat more approximate, for making estimates of discharges at dams throughout the world, even if the exact criteria and methods followed in their design vary from the standard designs for which the data are valid.

Weir equation

92. The discharge-versus-head relationship for flow over an uncontrolled ogee spillway is computed using the weir equation

$$Q = CLH_e^{1.5} \qquad (20)$$

Approach velocity is reflected in the energy head (H_e). The weir coefficient (C) is a function of energy head and submergence conditions as well as spillway shape. For a standard ogee design, the crest shape is set by the head (H_d) for which the spillway is designed. The effects of abutments and piers on discharge may be taken into account by reducing the net crest length to an effective length (L). Discharge (Q) is computed for a given water depth or head (H). Since H_e also includes velocity head which is a function of Q, an iterative solution is required. Flow over an ogee weir is illustrated by Figure 5.

31
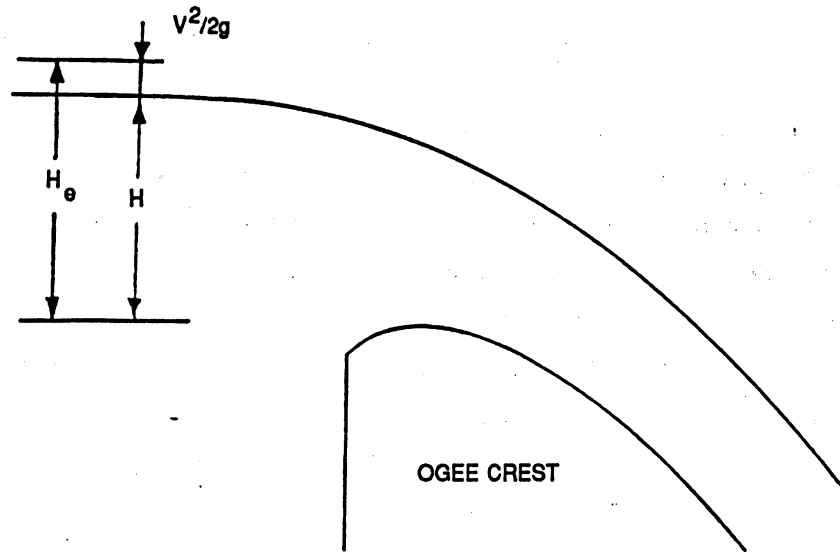
Figure 5. Flow over an ogee spillway crest

Discharge coefficients

93. The empirical data presented here are from the manual on hydraulic design of spillways (USACE 1965), which is based largely on a set of hydraulic design criteria developed and maintained at WES (USAE WES 1988).

94. Discharge coefficients are given as a function of the ratio of head to design head (H/H_d). H_d is set during design, and the shape of the spillway crest is a function of H_d. In many cases, H_d is set to correspond to the maximum reservoir level expected during the spillway design flood. For reasons of economy, crest shapes for high spillways have sometimes been designed for a H_d of 75 percent of the head for the maximum reservoir level of the spillway design flood. Hydrologic engineering methods are used to develop the spillway design flood, which typically represents maximum probable flooding conditions. The top of dam elevation is set by adding a freeboard to the spillway design flood maximum water surface elevation.

95. In military applications, the design head (H_d) for an existing dam will typically be estimated without benefit of the actual design records. The design head for a non-overflow dam will be somewhat less than the top of the dam, based on the original design including a freeboard allowance and possibly shaping the crest for a design head less than the maximum design water surface elevation. Consequently, an estimate of the design head can be made from the observed top of dam and spillway crest elevations. The discharge coefficients are not extremely sensitive to errors in estimating the design head. For

example, increasing the design head by 25 percent decreases the discharge coefficients and corresponding discharges by a range of 0-3.5 percent depending on the head (H).

96. A distinction is made between high-overflow spillways, which have a negligible velocity of approach, and low-overflow spillways, which have a significant velocity of approach that affects both the shape of the crest and the discharge coefficients. Discharge over a high-overflow spillway is also not affected by downstream submergence conditions.

97. With negligible velocity of approach, the energy head (H_e) term in the weir equation becomes simply the head (H). Figure 6 presents values of the discharge coefficient (C) as a function of H/H_d for the standard USACE high-overflow ogee design. The figure is based on a laboratory study conducted by WES and prototype data available from USACE District offices. C varies from a lower limit of 3.1 for H/H_d of 0.0, to 4.03 for H/H_d of 1.0. The lower limit of C of 3.1 is comparable to the theoretical value of 3.087 for a broad-crested weir. The upper range of discharge coefficient values is comparable to the coefficient for a sharp-crested weir. H/H_d of 1.33 corresponds to the maximum H for the spillway design flood for a design with H_d set as 75 percent of the maximum head during the spillway design flood.

98. Discharge coefficients for low overflow spillways are presented in Figure 7, which is also based on WES laboratory studies. A set of C versus H_e/H_d curves is provided for alternative ratios of crest height (P) to design head (H_d). A spillway with a P/H_d ratio of 1.33 or greater is considered a high overflow spillway, and the discharge coefficient no longer varies with P/H_d. The curve in Figure 7 for P/H_d of 1.33 is identical to the curve in Figure 6.

99. The curves in Figure 7 are coded into the RESOUT model in table format. To apply this option, the user must specify values for H_d and P. The program uses linear interpolation to obtain values from the table. Alternatively, the user may input his own table of C versus H/H_d to the computer program.

Approach velocity head

100. The energy head (H_e) includes the water depth (H) over the crest and the approach velocity head ($V^2/2g$) as follows

LEGEND

O WES AVERAGE TEST POINTS   H/H$_d$>0.3
● FORT GIBSON   (MODEL)
▲ FORT RANDALL
▼ HARLAN COUNTY   H/H$_d$<0.4
+ PINE FLAT   (PROTOTYPE)
■ WOLF CREEK
X DALE HOLLOW

H = H$_d$

C = 4.03

$C = Q/LH^{3/2}$
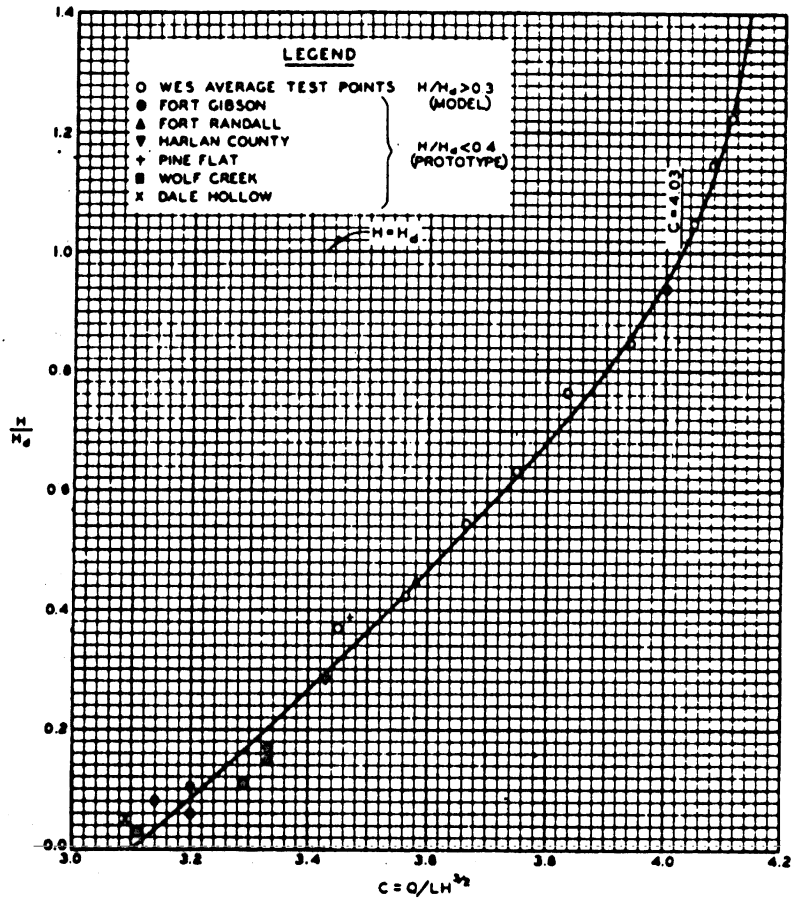
NOTE: H = HEAD ON CREST, FT.
      H$_d$ = DESIGN HEAD, FT.
      Q = DISCHARGE, CFS.
      L = NET LENGTH OF CREST, FT.

HIGH OVERFLOW SPILLWAYS
DISCHARGE COEFFICIENT

Figure 6. Discharge coefficient for high ogee spillways
(Source: HDC 111-3 (USACE 1988) and EM 1110-2-1603
(USACE 1965))

34
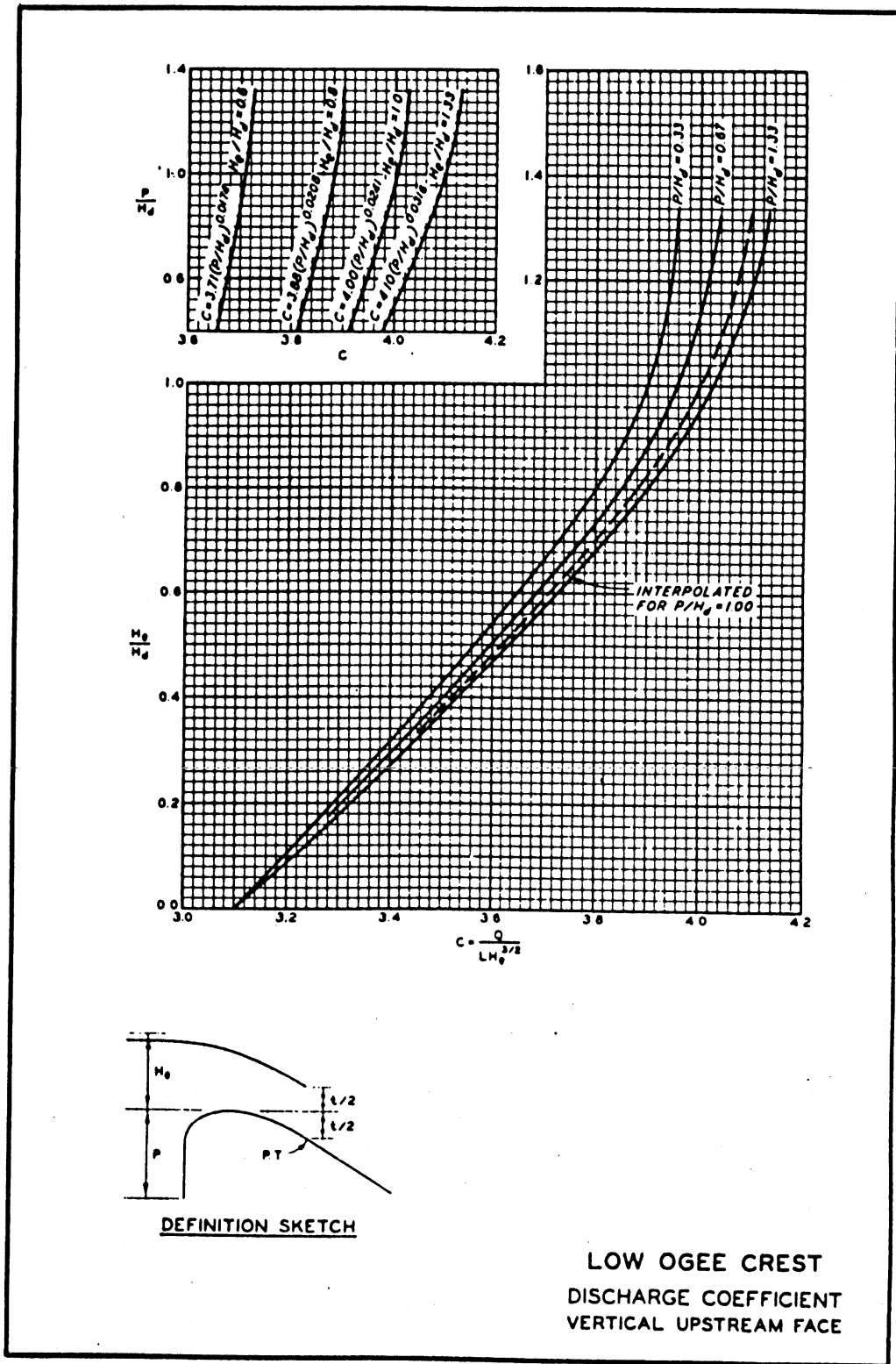
Figure 7. Discharge coefficient for low ogee spillways
(after HDC 122-1 (USACE 1988) and EM 1110-2-1603
(USACE 1965))

$$H_e = H + V^2/2g \qquad (21)$$

The approach velocity (V) is computed as

$$V = Q/A \qquad (22)$$

where

$$A = (P_o + H) W$$

assuming the approach channel can be approximated as rectangular in shape with an approach depth $(P_o + H)$ and width (W). The approach depth includes head over the spillway crest (H) and depth below the crest (P_o).

101. An iterative solution of the weir equation is required. For a given head (H), zero velocity is assumed to start the computations. Q is computed with the weir equation. This Q, as computed assuming zero velocity head, is then used to estimate a velocity head. Q is then recomputed. The velocity head can continue to be iteratively corrected until changes no longer occur.

102. RESOUT performs the computations with P_o and W provided as input data. Spillways at some reservoirs have a well-defined approach channel. In other cases, the entire reservoir width may be considered as the approach to the spillway. However, engineering judgment is typically required to delineate an effective area through which significant flow to the spillway will occur. The section should extend through the point at which the head (H) is defined.

Correction for upstream face slope

103. The curves in Figure 7 are for an ogee spillway with a vertical upstream face. Figure 8 shows the effects on discharge of a sloping upstream face (USBR 1977b). The ratio of the discharge coefficient for an ogee crest with a sloping upstream face to the coefficient for a vertical face is plotted versus P/H_o, where P is the crest height and H_o is the design energy head. For small ratios of approach depth to head on the crest, sloping the upstream face of the spillway results in an increase in the coefficient of discharge. For large P/H_o ratios, the effect is a decrease in the discharge coefficient. Although Figure 7 is expressed in terms of design energy head (H_o), the curves can be used for energy heads (H_e) other than the design energy head. The
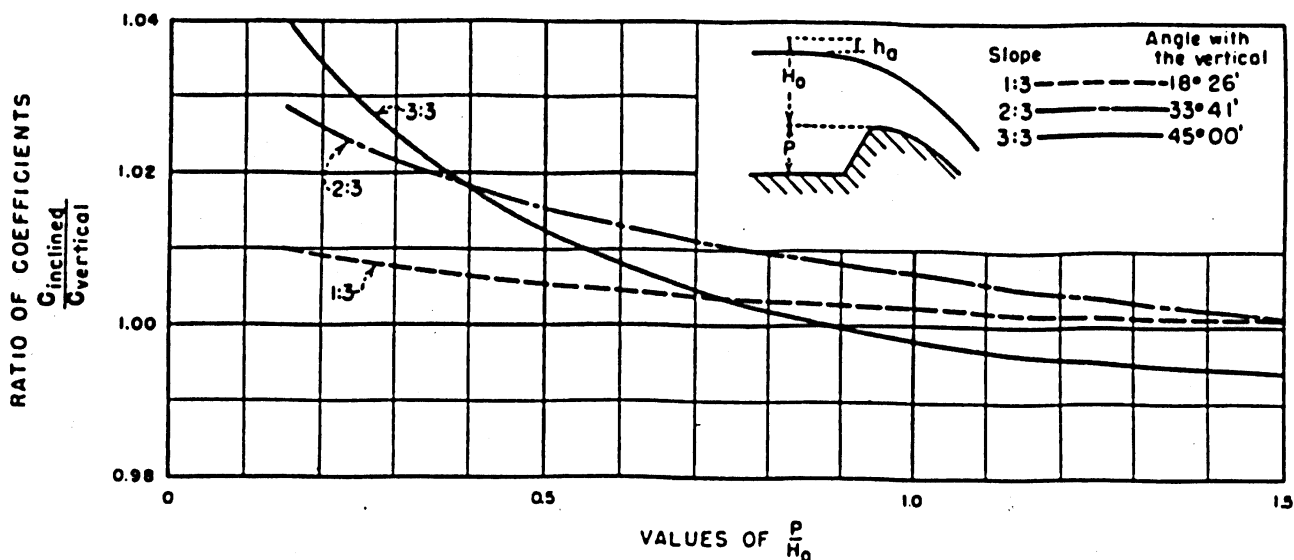
Figure 8. Ogee spillway discharge coefficient correction for sloping
upstream face (after USBR (1977) Figure 251)

RESOUT computer program allows the user to enter correction factors by which
the discharge coefficients are multiplied.

Submerged flow

104. A weir is said to be submerged when the tailwater is higher than
the crest. Although spillways are typically not submerged, this flow condi-
tion can occur at low dams. Submergence causes flow to become unstable, and
the accuracy of discharge predictions is decreased.

105. Extensive studies on submerged ogee weirs were performed by the
USBR (1948). The chart reproduced in Figure 9 was originally developed from
these studies and later verified and modified by WES. The chart is based on
201 experimental data points. Figure 9 shows the reduction in discharge coef-
ficient caused by submerged flow conditions. Other approaches for determining
the effects of submergence on weir coefficients are outlined by Brater and
King (1976).

106. In Figure 9, the percent decrease in discharge coefficient is
expressed as a function of the terms h_d/H_e and $(h_d + d)/H_e$, which includes
tailwater depth (d), the vertical distance from the tailwater elevation to the
reservoir water surface elevation (h_d), and energy head (H_e). With these
variables known, the percent decrease in discharge coefficient is determined
from the chart. The free or unsubmerged discharge coefficient is then reduced
by this percentage.

SUBMERGED CREST COEFFICIENTS

OVERFLOW CRESTS

HYDRAULIC DESIGN CHART III-4

WES 4-1-53
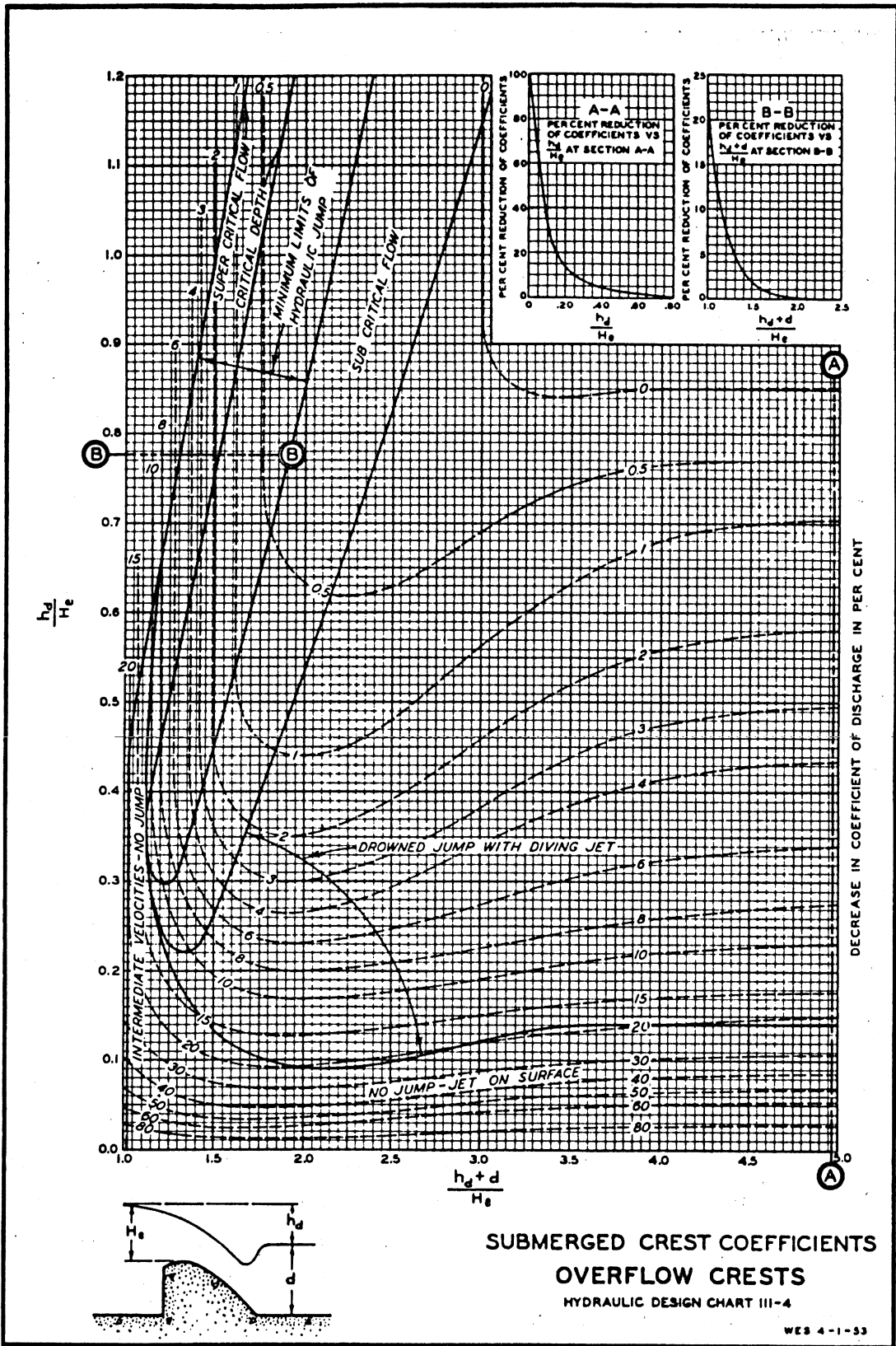
Figure 9. Ogee spillway discharge coefficient correction for submerged flow (after HDC 111-4 (USACE 1988) and EM 1110-2-1603 (USACE 1965) Plate 33)

107. In the studies that led to development of the chart, flow was categorized based on the flow condition prevalent on the downstream apron; i.e., (a) supercritical flow, (b) subcritical flow involving hydraulic jump, (c) flow accompanied by a drowned jump with diving jet, and (d) flow approaching complete submergence. The general pattern of the curves shows that, for low ratios of $(h_d + d)/H_e$, the flow is supercritical and the reduction in discharge coefficient is affected primarily by this ratio and is practically independent of h_d/H_e. The cross section BB in the upper right corner of the chart shows the variation of $(h_d + d)/H_e$ for h_d/H_e of 0.78. On the other hand, for large values of $(h_d + d)/H_e$, the reduction in discharge coefficient is affected primarily by the ratio h_d/H_e. Under this condition, for values of h_d/H_e less than 0.10, the flow approaches complete submergence. For values of h_d/H_e greater than 0.10, the flow is accompanied by a drowned jump with diving jet. The cross section AA shows the variations of h_d/H_e at $(h_d + d)/H_e$ near 5.0. Subcritical flow occurs in the region indicated on the chart. Other regions for transitional flow conditions are also shown.

108. Figure 9 is coded into the RESOUT computer program in the form of a table, which was previously developed and incorporated into the HEC-1 Flood Hydrograph Package (US Army Engineer Hydrologic Engineering Center 1985). The table included in HEC-1 and RESOUT is shown here as Table 1. RESOUT reads the table using linear interpolation.

109. A tailwater depth (d) is required for the submerged flow computations. RESOUT computes the tailwater depth using the Manning equation and user-supplied cross-sectional geometry. A representative downstream cross section is defined by an inputted channel top width-versus-elevation table and a value for the Manning roughness coefficient (Tables 2 and 3). Alternatively, a tailwater depth-versus-discharge table can be provided as input to RESOUT. If the tailwater is significantly affected by downstream backwater effects, the tailwater depth-versus-discharge relationship can be developed using a backwater model such as the HEC-2 computer program (US Army Engineer Hydrologic Engineering Center 1982).

Abutment and pier contractions

110. Piers are constructed to form the sides of the gates in gated spillways. Piers may also support a roadway over the spillway or serve other purposes. The hydraulic effect of piers is to contract the flow and, thus, to alter the effective crest length of the spillway. Flow contractions also occur at the abutments on either end of the spillway crest.

Table 1

Submergence Coefficient

1.07	1.10	1.15	1.20	1.30	1.40	1.50	1.60	(ME + D)/ME 1.70	1.80	1.90	2.00	2.25	2.50	3.00	3.50	4.00	4.50	MD/ME
						PERCENT SUBMERGENCE												
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.00	100.00	100.00	100.000	100.000	100.000	100.000	100.000	100.00	100.00	100.0	.00
55.0	54.0	52.0	49.0	45.0	42.0	40.0	39.00	38.00	38.00	37.500	39.000	40.500	43.000	53.000	58.00	60.00	60.0	.05
36.5	35.0	33.0	31.0	27.0	23.5	21.0	19.00	18.50	18.00	18.785	18.880	19.520	21.150	26.250	29.00	31.00	32.0	.10
27.5	25.0	22.0	19.5	17.5	15.5	14.0	13.50	13.00	12.50	12.450	12.210	12.630	13.440	15.000	17.00	18.30	21.0	.15
21.0	18.0	17.0	15.0	13.0	11.3	9.8	8.50	8.50	8.20	8.000	8.000	8.190	8.560	9.410	11.20	12.00	13.0	.20
18.0	15.5	13.5	12.0	10.0	8.4	7.2	5.40	5.40	5.00	4.900	4.914	5.375	5.888	7.000	7.85	8.50	9.0	.25
16.0	13.5	12.0	10.5	8.0	6.1	4.3	3.30	3.30	3.10	3.000	3.020	3.333	3.820	5.123	6.08	6.66	7.0	.30
15.0	13.0	10.0	8.0	5.5	3.6	2.5	1.70	1.70	1.50	1.450	1.438	1.625	1.888	2.717	3.73	4.19	4.5	.40
15.0	13.0	10.0	8.0	5.5	3.3	2.0	0.96	0.96	0.87	0.857	0.842	0.853	0.933	1.620	2.24	2.70	2.9	.50
15.0	13.0	10.0	8.0	5.5	3.3	2.0	0.90	0.90	0.75	0.525	0.515	0.562	0.600	0.860	1.27	1.65	1.8	.60
15.0	13.0	10.0	8.0	5.5	3.3	2.0	0.80	0.80	0.50	0.475	0.450	0.390	0.385	0.470	0.69	0.93	1.0	.70
15.0	13.0	10.0	8.0	5.5	3.3	2.0	0.70	0.70	0.49	0.450	0.415	0.323	0.250	0.110	0.20	0.34	0.3	.80
15.0	13.0	10.0	8.0	5.5	3.3	2.0	0.70	0.70	0.49	0.445	0.410	0.310	0.220	0.030	0.00	0.00	0.0	.85
15.0	13.0	10.0	8.0	5.5	3.3	2.0	0.70	0.70	0.49	0.445	0.400	0.300	0.200	0.000	0.00	0.00	0.0	.90

Source: HEC-1 Users Manual (USACE 1985)

Table 2

Manning Roughness Coefficient Range

Type of Conduit	Roughness Coefficient (n)	
	Minimum	Maximum
Concrete conduit	0.008	0.014
Steel pipe with welded joints	0.008	0.012
Unlined rock tunnel	10.020	0.035

Source: USBR (1977)

Table 3

Observed Values of Manning Roughness Coefficient

Type of Conduit	Roughness Coefficient (n)
Reynolds Number Near 10^8	
Concrete, wood forms, joints ground (Oahe)	0.0098
Concrete, steel forms (Denison)	0.0103
Steel, coal tar (Fort Randall)	0.0114
Reynolds Number Near 10^7	
Steel, vinyl (Fort Randall)	0.0107
Concrete, wood forms (Enid)	0.0125
Concrete, wood forms (Pine Flat)	0.0115
Concrete, wood forms, roughed with use (Pine Flat)	0.0135

Source: EM 1110-2-1602 (USACE 1963)

111. The contraction effects of abutments and piers can be accounted for by using an effective length (L) in the weir equation, determined as follows:

$$L = L - 2(NK_p + K_a)H_e \tag{23}$$

where

      L — net length of the spillway excluding the total width of piers

      N — number of piers

      K_p — pier coefficient

      K_a — abutment coefficient

      2 — number of contractions per gate bay

112. Figure 10 is a plot of abutment contraction coefficient (K_a) as a function of H_e/R for an overflow spillway crest with adjacent concrete sections, where R is the radius of the abutment in feet. Figure 11 is a plot of K_a versus H_e/H_d for an overflow spillway crest with adjacent earth embankment sections.

113. When spillways are operated with one or more bays closed, the piers adjacent to these bays produce abutment-type effects and result in greater flow contractions than when the flow is evenly divided around the piers. Figure 10 can also be used to estimate contraction coefficients when piers function essentially as abutments because of closed bays.

114. Figure 12 is a pier coefficient chart developed based on the results of tests conducted at WES. Pier contraction coefficients (K_p) are plotted versus H_e/H_d for five different pier-nose shapes.

115. Figures 10, 11, and 12 are coded in RESOUT in table format and are read by the program using linear interpolation. Alternatively, user-specified abutment and pier contraction coefficients (k_a and k_p) can be provided as input data.
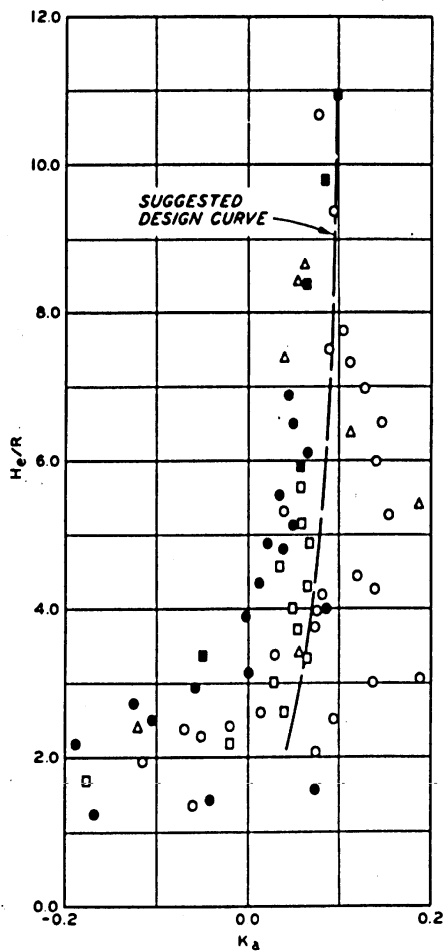
The chart contains the following text:

BASIC EQUATION

$$Q = C\left[L' - 2\left(NK_P + K_A\right)H_e\right]H_e^{3/2}$$

WHERE:
Q = DISCHARGE, CFS.
C = DISCHARGE COEFFICIENT.
L' = NET LENGTH OF CREST, FT.
N = NUMBER OF PIERS.
K_P = PIER CONTRACTION COEFFICIENT.
K_A = ABUTMENT CONTRACTION COEFFICIENT.
H_e = TOTAL HEAD ON CREST, FT.

LEGEND

SYMBOL	PROJECT	R	W/L	W/H
O	CW 801	4	1.55	0.96
●	FOLSOM	8	2.10	3.77
□	PHILPOTT	5	2.67	1.42
■	PINE FLAT*	4	2.12	1.77
Δ	CENTER HILL*	5	3.83	9.48

*GATED SPILLWAY WITH PIERS

NOTE: R = RADIUS OF ABUTMENT, FT.
W = WIDTH OF APPROACH REPRODUCED IN MODEL, FT.
L = GROSS WIDTH OF SPILLWAY, FT.
H = DEPTH OF APPROACH IN MODEL, FT.

SUGGESTED DESIGN CURVE

H_e/R (vertical axis: 0.0 to 12.0)
K_A (horizontal axis: -0.2 to 0.2)
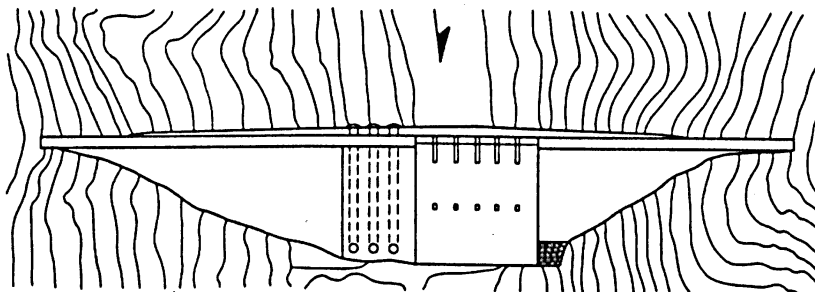
OVERFLOW SPILLWAY CREST WITH
ADJACENT CONCRETE SECTIONS

ABUTMENT CONTRACTION COEFFICIENT

HYDRAULIC DESIGN CHART III-3/1

WES 8-60

Figure 10. Abutment contraction coefficient for concrete sections
(after HDC 111-3/1 (USACE 1988) and EM 1110-2-1603 (USACE 1965)
Plate 8)
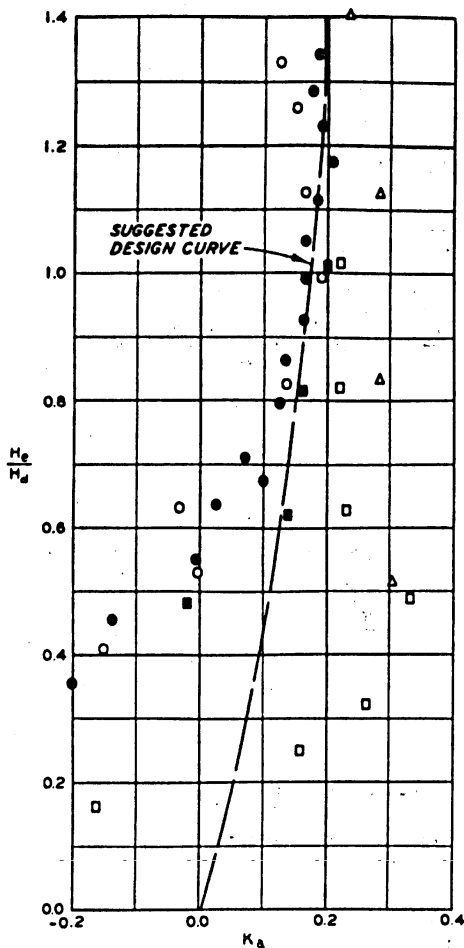
BASIC EQUATION

$$Q = C\left[L' - 2(NK_p + K_a)H_e\right]H_e^{3/2}$$

WHERE:
Q = DISCHARGE, CFS
C = DISCHARGE COEFFICIENT
L' = NET LENGTH OF CREST, FT
N = NUMBER OF PIERS
K_p = PIER CONTRACTION COEFFICIENT
K_a = ABUTMENT CONTRACTION COEFFICIENT
H_e = ENERGY HEAD ON CREST, FT

LEGEND

SYMBOL	PROJECT	R	W/L	W/H
□	DORENA	2	5.60	10.7
■	DORENA	4	5.60	10.7
○	RED ROCK *	7.8	3.42	16.5
●	CARLYLE *	9	8.44	75.5
△	WALTER F. GEORGE *	4	5.44	55.3

*GATED SPILLWAY WITH PIERS

NOTE: R = RADIUS OF ABUTMENT, FT
W = WIDTH OF APPROACH REPRODUCED IN MODEL, FT
L = GROSS WIDTH OF SPILLWAY, FT
H = DEPTH OF APPROACH IN MODEL, FT
H_d = DESIGN HEAD ON CREST, FT
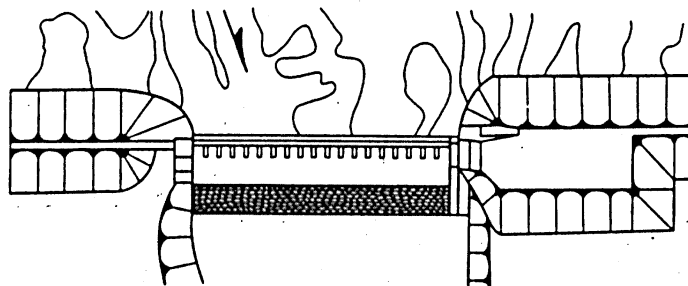
OVERFLOW SPILLWAY CREST WITH ADJACENT EMBANKMENT SECTIONS

ABUTMENT CONTRACTION COEFFICIENT

HYDRAULIC DESIGN CHART III-3/2

PREPARED BY U S ARMY ENGINEER WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI REV 1-64   WES 8-60

Figure 11. Abutment contraction coefficient for embankment sections
(after HDC 111-3/2 (USACE 1988) and EM 1110-2-1603 (USACE 1965)
Plate 37)
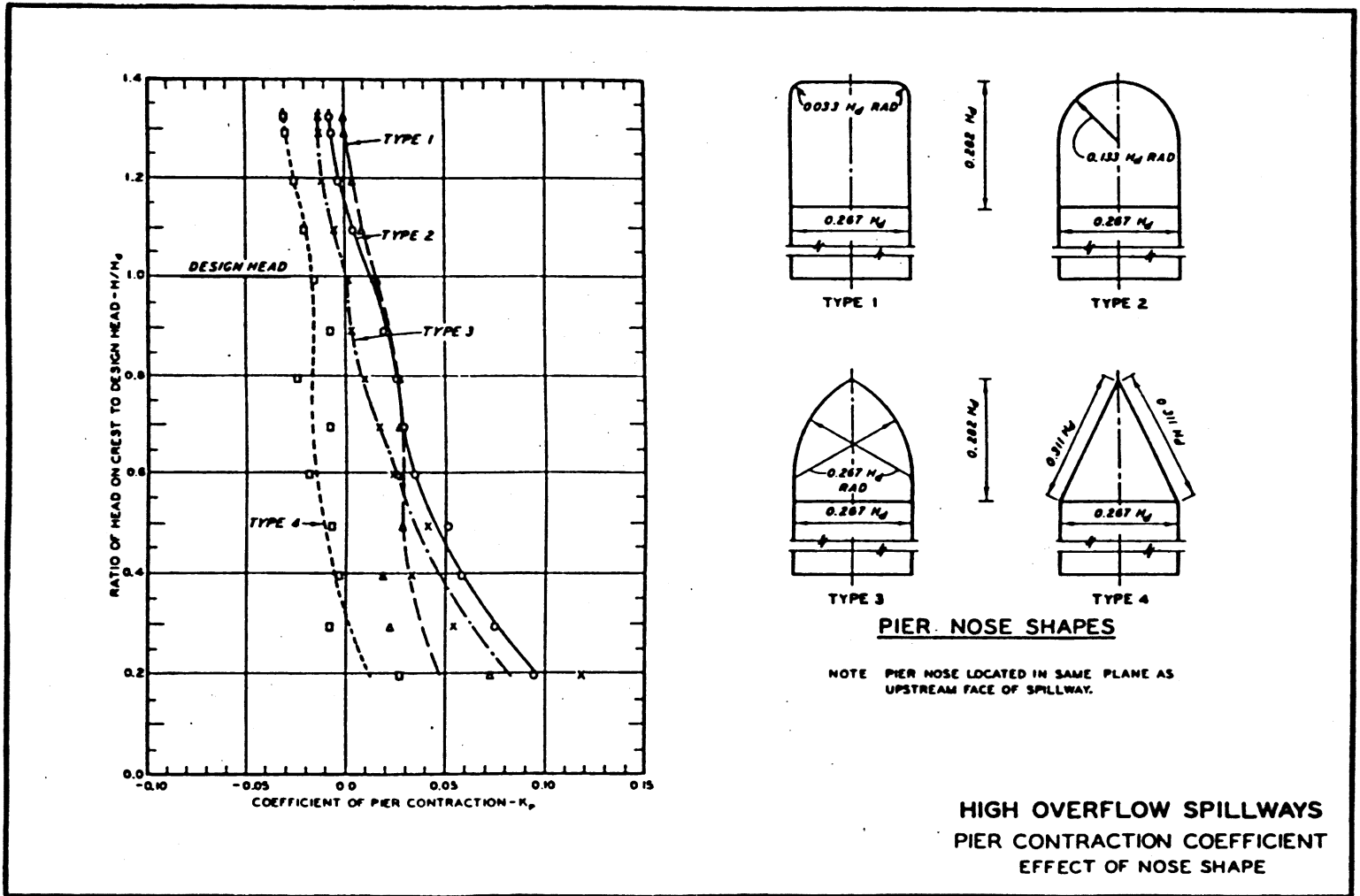
Figure 12. Pier contraction coefficient (after HDC 111-5 (USACE 1988) and EM 1110-2-1603 (USACE 1965) Plate 7)

Rating Curves for Uncontrolled Broad-Crested Spillways

116. Various types of spillways have crests which are simple broad-crested weirs. Discharge through a broad-crested spillway or other structures involving weirs is computed using the weir equation

$$Q = CLH^{1.5} \tag{11}$$

for a rectangualr weir, where L is the weir length and H is head, or

$$Q = CZH^{2.5} \tag{24}$$

for a triangular weir, where Z is the side slope of the notch, or

$$Q = C_1LH^{1.5} + C_2ZH^{2.5} \tag{25}$$

for a trapezoidal-shaped weir, where the first term represents the rectangular and the second term the triangular components of the trapezoid.

117. Discharge coefficient (C) values of 3.1 for rectangular and 2.45 for triangular weirs or triangular components of trapezoidal weirs are typically considered to be conservatively high but reasonable values, assuming units of feet and cubic feet per second are used in the weir equation. The discharge coefficient values would be 1.71 and 1.35, respectively, for rectangular and triangular weirs if units of metres and cubic metres per second are used.

118. The RESOUT model applies correction factors to the weir equation for approach velocity (k_v) and submergence (k_s) effects as follows.

$$Q = k_v k_s CLH^{1.5} \tag{26}$$

119. The approach velocity correction factor (k_v) is given by the following equation, which was developed by Fread (1984) from data presented by Brater (1959).

$$k_v = 1.0 + 0.023 \, Q^2/[W^2(P_o + H)^2 H] \tag{27}$$

assuming the approach channel can be approximated as rectangular in shape with an approach depth (P_o+H) and width (W). The approach depth includes head over the spillway crest (H) and depth below the crest (P_o).

120. The submergence correction factor (k_s) is given as follows (Fread 1984 and Vennard 1954).

$$k_s = 1.0 \; if \; h_t/H = 0.67 \tag{28}$$

$$k_s = 1.0 - 27.8 \, [(h_t/H) - 0.67]^3 \tag{29}$$

where h_t is the height of the tailwater over the weir crest and H is the height of the reservoir water surface over the weir crest. RESOUT computes tailwater depth using the Manning equation and user-supplied cross-sectional geometry for a representative downstream cross section. Alternatively, a tailwater depth versus discharge table can be provided as input to RESOUT.

Rating Curves for Spillway Gates

121. RESOUT includes two approaches for developing rating curves for partly open spillway gates. Both approaches are based on forms of the orifice equation.

122. The basic equation for a high head orifice with a free-falling nappe is

$$Q = CA(2gH)^{0.5} \tag{30}$$

where Q denotes discharge, C is the discharge coefficient, A denotes orifice area, and H is the head measured from the center of the orifice. This equation is incorporated in RESOUT and can be used for various types of gates. The empirical discharge coefficient data discussed later were developed specifically for tainter gates on ogee spillways.

123. Another orifice equation applicable to flow through a rectangular orifice with a low ratio of head to orifice height is

$$Q_G = C_d(2g)^{0.5}L(H^{1.5} - H_T^{1.5})$$ (31)

where H and H_T are the head to the bottom and top, respectively, of the orifice. The vertical lift gate analysis approach discussed below is based on this form of orifice equation.

Vertical lift gates

124. The basic equation for flow through a rectangular orifice with a low ratio of head-to-orifice height given above can be combined with the equation for flow over a weir

$$Q = C(2g)^{0.5} LH^{3/2}$$ (32)

to obtain

$$Q_G/Q = \mu\{1 - [(H - G_o)/H]^{1.5}\}$$ (33)

where μ is the ratio C_d/D and G_o is the gate opening H_t-H.

125. Figure 13 is a plot of experimental data of the ratio Q_G/Q against the bracketed term in the equation above for vertical lift gates on ogee spillways (USACE 1965). The slope of the line represents the coefficient μ. A study at WES based on available model results indicates that $\mu = 1.14$ for low heads ($H/H_d \leq 0.5$) and 1.04 for high heads ($H/H_d = 1.0$). The curves can be interpolated for H/H_d values between 0.5 and 1.0.

126. The RESOUT computer program includes the above equation. The free overflow Q is computed using the weir equation. The coefficient is determined based on a computed H and user-inputted H_d. The term in brackets is computed based on a user-inputted G_o. The discharge through the gate opening is then computed as
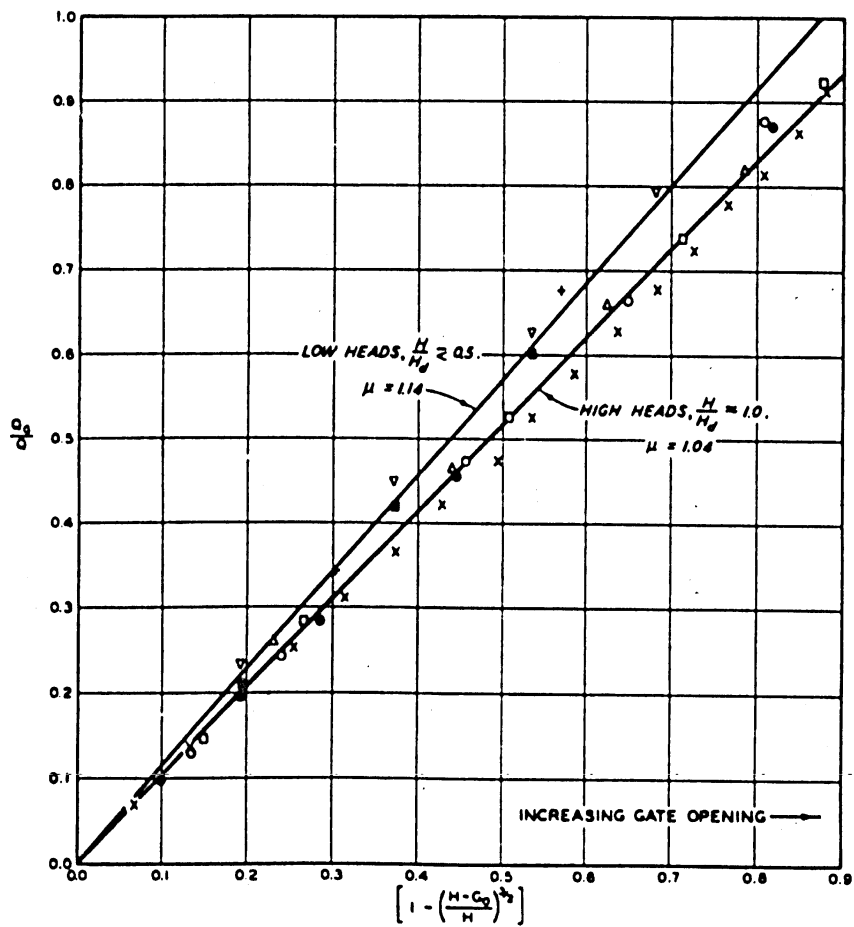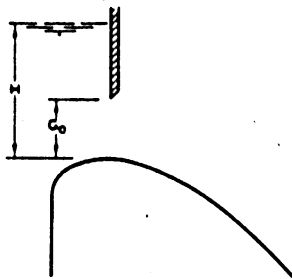
Figure 13. Vertical lift gate discharge coefficient
(after HDC 312 (USACE 1988) and EM 1110-2-1603
(USACE 1965) Plate 49)

$$Q_G = (1 - [(H - G_o)/H]^{1.5})Q \qquad (34)$$

127. As the gate is raised, the ratio of head on the gate to the total head becomes smaller, and the abscissa in Figure 13 becomes larger. The nappe breaks free from the gate lip at an abscissa value of about 0.9. The corresponding ratio of head on the gate to head on the crest is about 0.21. The value for the transition from orifice flow to free overflow when the gate is raised is probably different from the reverse transition when the gate is lowered. When the gate lip extends only a small distance into the flow, there is a violent top roller and the transition phenomenon is difficult to observe.

Tainter gates

128. Discharge coefficients applicable to tainter gates on high overflow ogee spillways are presented in Figure 14 for the orifice equation in the form

$$Q = CG_oB(2gH)^{0.5} \qquad (35)$$

where

G_o — net gate opening in feet

B — is the gate width in feet

H — head-to-center-of-the-gate opening in feet

Two discharge coefficient curves are presented, one for gate seats located at the crest axis and a second for gate seats located at $0.1 \leq X/H_d \leq 0.3$, where X is the horizontal distance between the crest axis and gate seat. The value of C ranges from 0.67 to 0.73 for various gate openings.

129. The flow boundaries formed by the gate and crest surfaces are comparable to those of a funnel or an orifice formed by converging plane surfaces. The discharge coefficient (C) is a function of the angle (ϕ) formed by the intersection of the tangent to the gate lip and the tangent to the crest curve at the nearest point of the curve to the gate lip.

130. RESOUT requires user-specified discharge coefficient values to be inputted for each gate opening considered using this option. Discharge coefficients for tainter gates on ogee-shaped spillway crests can be estimated based on judgment using the data presented in Figure 14 as a general guide.
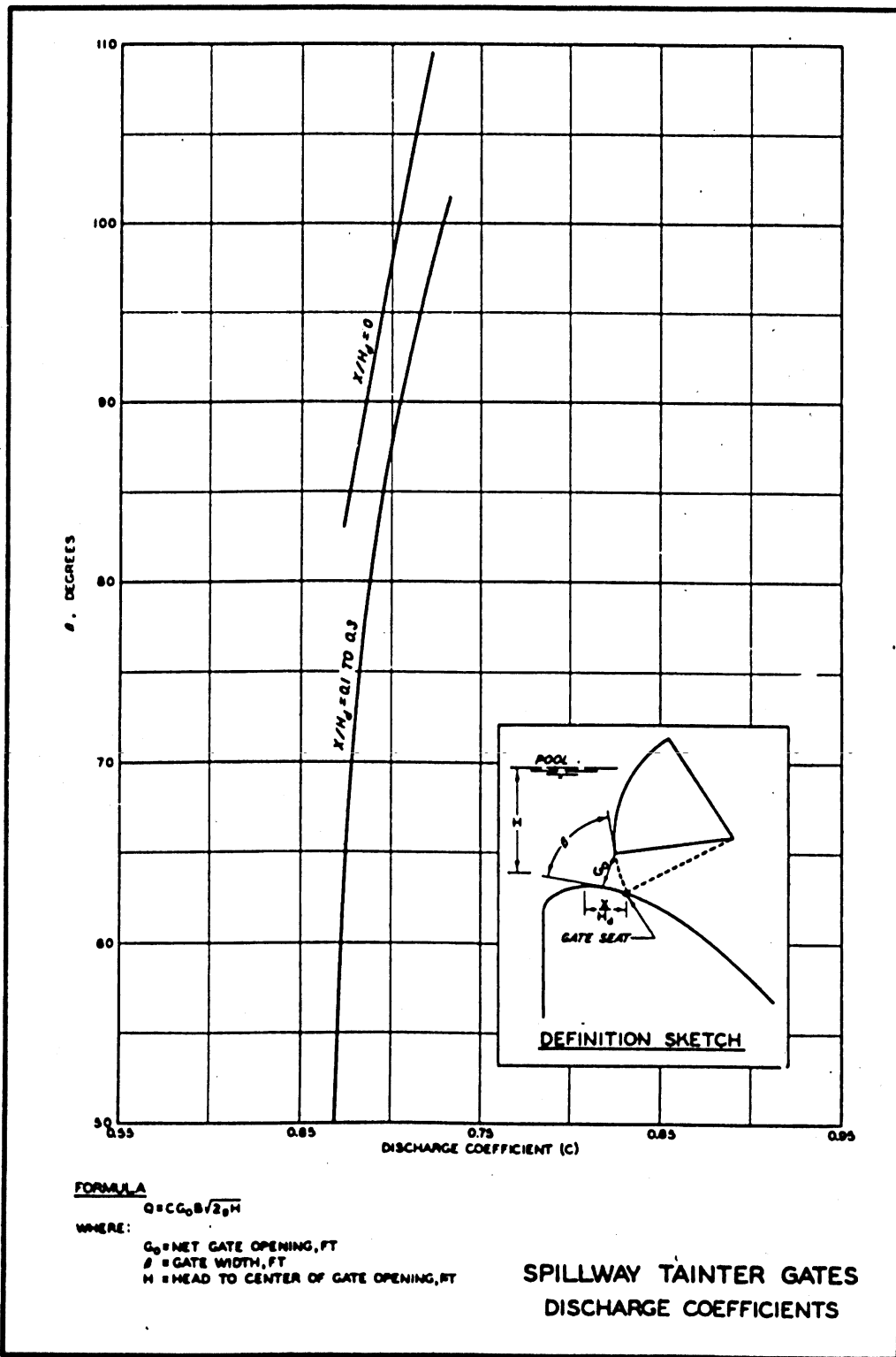
Figure 14. Tainter gate discharge coefficient
(after HDC 311-1 (USACE 1988) and EM 1110-2-1603
(USACE 1965) Plate 46)

Other types of gates can be analyzed with RESOUT as well, with the hydraulic efficiency of the gate configuration being reflected in the inputted discharge coefficient value.

Drop Inlet Spillways

131. The drop inlet spillway, also known as the morning-glory or shaft spillway, is illustrated in Figure 15. The outflow is conveyed by a vertical or sloping shaft to a horizontal tunnel or conduit through the dam. Both the ogee crest and the flat or broad-crested shapes have been used for the entrance weir. The ogee crest has the advantage of hydraulic efficiency.

132. Drop inlet spillways may operate under both free and submerged discharge conditions. For small heads, discharge through the spillway is controlled by flow conditions at the crest. The vertical transition below the crest will flow partly full and the flow will cling to the sides of the shaft. As the flow over the crest increases, the annular nappe will become thicker and eventually the nappe flow will converge into a solid vertical jet, as illustrated by Figure 15. The point where the annular nappe joins the solid jet is called the crotch. After the solid jet forms, a boil will occupy the region above the crotch. Both the crotch and the top of the boil become progressively higher with larger discharges. For high heads, the crotch and boil may flood out, showing only a slight depression and eddy at the surface.

133. Free discharge weir flow prevails until the nappe converges to form a solid jet. The weir flow will be affected by submergence after the crotch and boil form. Ultimately the crest will drown out. At less than design heads, the transition from free to submerged flow and vice versa may be accompanied by violent surging in the vertical shaft.

134. The discharge through a drop inlet spillway can be computed using the modified weir equation

$$Q = C(2 R)H^{1.5} \tag{36}$$
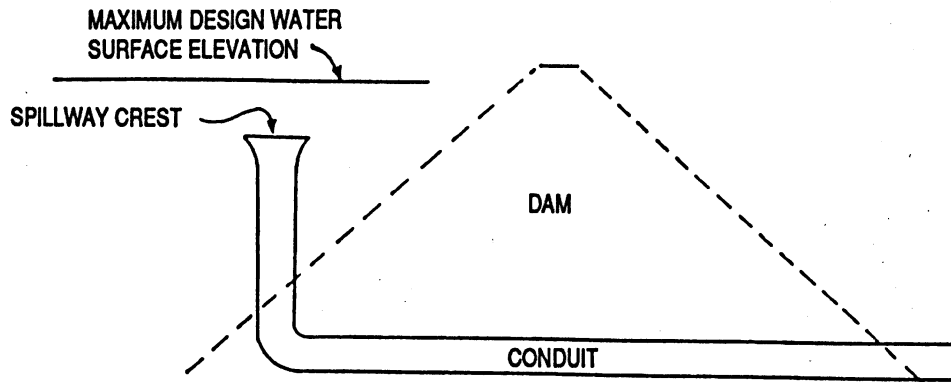
a. Spillway profile
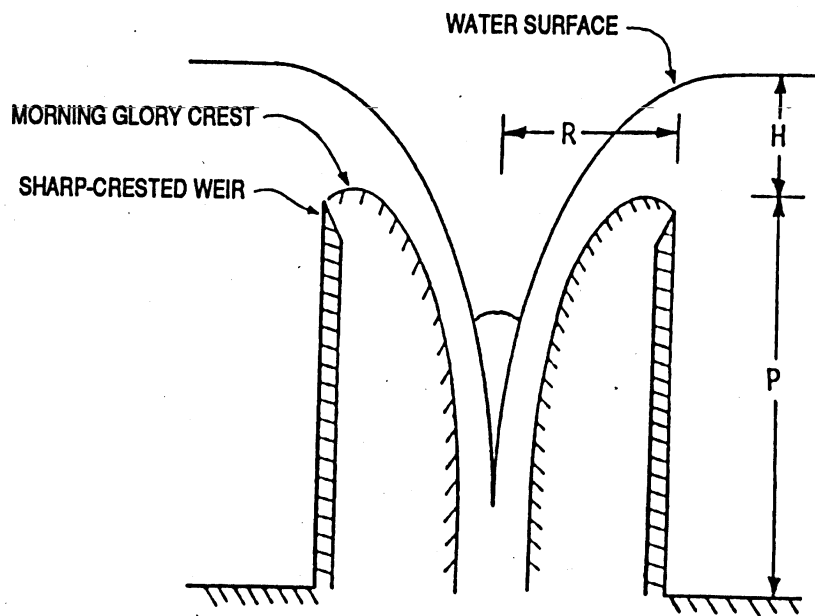
b. Section through spillway entrance

Figure 15. Drop inlet spillway schematic

135. The above equation is included in RESOUT. C and R must be provided by the user as input data.

136. The discharge coefficient C is difficult to precisely estimate. Discharge coefficients based on flow measurements over sharp-crested weirs are presented in Figure 16. This data, published by the USBR (1977) and reproduced by USACE (1965), can be used as general guidance for estimating discharge coefficients for drop inlet spillways with circular ogee-shaped entrances.

137. Figure 16 is a plot of C versus H_d/R for an ogee spillway crest. C depends upon the ratio of the approach depth (P_0) to the radius (R). These spillway dimension terms are defined schematically in Figure 15. The coefficients in Figure 16 are for the design head. The coefficients (C) are valid for both free and submerged flow conditions. Free flow prevails for H_d/R ratios up to approximately 0.45. As the H/R ratio increases above 0.45, partial submergence occurs. When the H/R ratio approaches 1.0, the weir is completely submerged. With submerged flow, a further increase in head on the crest results in a comparatively small increase in discharge.

138. Figure 16 is for the design head. For purposes of developing a rating curve, Figure 16 can be used in combination with Figure 17 (USBR 1977). The discharge coefficient corresponding to a H_d/R ratio of 0.3 is determined from Figure 16. Ratios of the coefficient of discharge for a specified head to the Figure 16 value for H_d/R of 0.3 are given in Figure 17 as a function of H/R.

Rating Curves for Outlet Works

139. An outlet works consists of one or more conduits or sluices through the dam, and associated intake and exit structures. Gates and valves are incorporated into an outlet works to control the flow rate. Methods for analyzing flow through a conduit vary depending on whether the conduit is flowing full or partly full. If the water surface stays below the top of the conduit, the conduit becomes an open channel, and the flow is governed by principles of open channel flow. The hydraulics of a conduit flowing full are governed by pressure conduit flow. The computational procedures incorporated in RESOUT are for conduits flowing full.
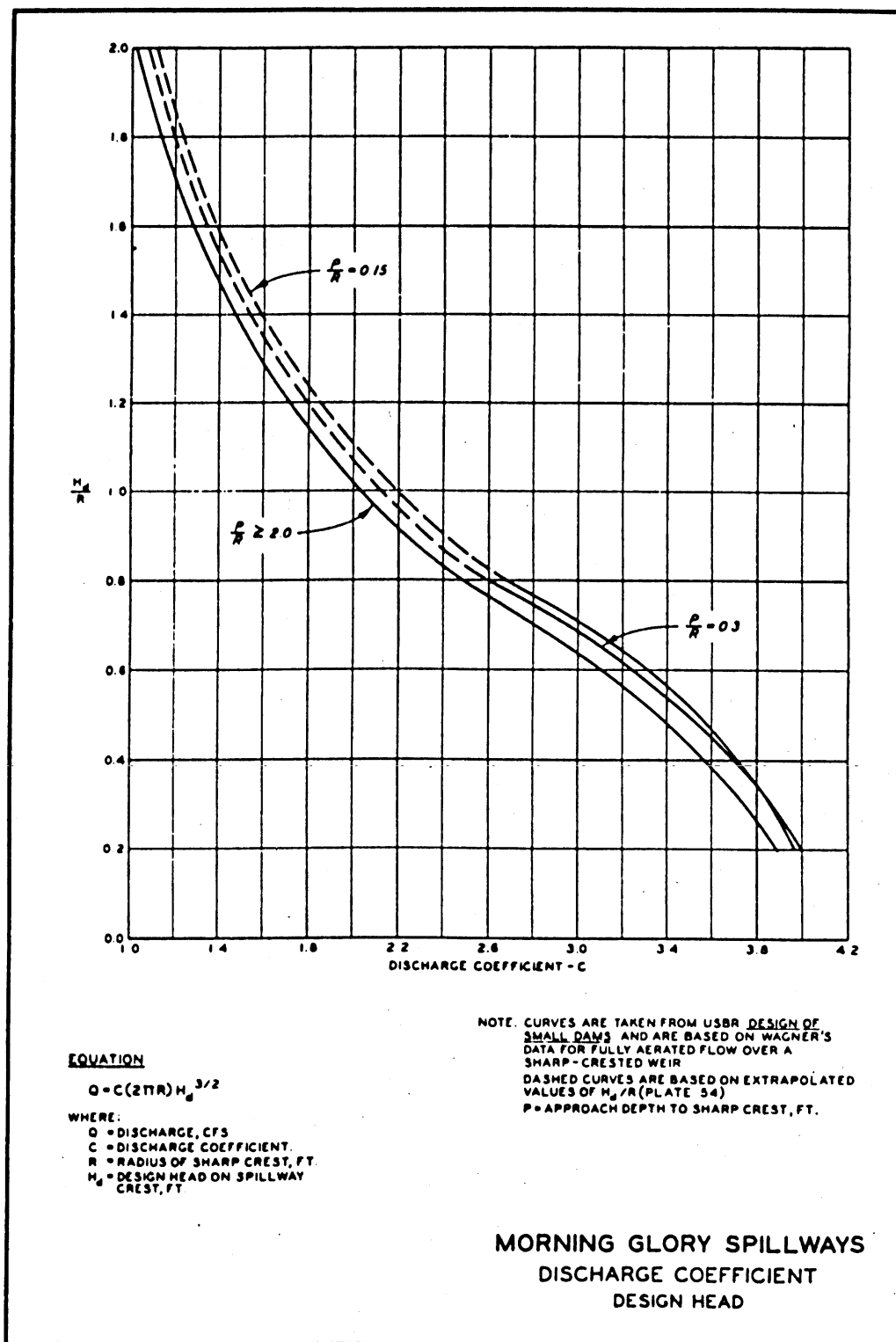
Figure 16. Drop inlet spillway discharge coefficient for design
head (after USBR (1977b) and EM 1110-2-1603 (USACE 1965) Plate 55)

Conduits flowing partly full

140. The discharge in a con-
duit flowing partly full, without
gate control, is governed by the same
principles which apply to flow in
open channels. In some cases, a gate
portal or other component of the out-
let structure may cause weir flow to
occur, and discharge can be estimated
with the weir equation. For uniform
flow conditions, the Manning equation
is used to relate discharge to flow
depth. If backwater or drawdown con-
ditions result in gradually varied nonuniform flow, the step method solution
of the energy equation, with head losses estimated with the Manning equation,
is used to determine the water surface profile for a given discharge. This
method is described by most hydraulics books, including Linsley and Franzini
(1979) and French (1985).

Figure 17. Drop inlet spillway
discharge coefficient correction
for other than design head (after
USBR (1977b) Figure 284)

Conduits flowing full

141. The head loss in an outlet works is the difference between head at
the entrance and exit, which is typically taken to be the reservoir water
surface elevation minus the elevation of the water surface or zero pressure
elevation in the exit portal, with the exit velocity head being treated as
part of the head loss. Head loss is a function of discharge. Thus, discharge
is related to reservoir water surface elevation by computing head losses
occurring in the outlet structure.

142. A head loss coefficient (K) is defined in terms of velocity head
as follows.

$$H = K(V^2/2g) \qquad (37)$$

Substituting V = Q/A, this equation can be written in the form of an orifice
equation

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$$Q = A(2gH/K)^{0.5} \qquad (38)$$

where A is the conduit cross-sectional area. The factor $(1/K)^{0.5}$ is analogous to the orifice discharge coefficient. K is a total-loss coefficient which typically will be the sum of several component-loss coefficients

$$K = k_1 + k_2 + k_3 + \ldots \qquad (39)$$

where k_i represents loss coefficients for outlet structure components such as trashracks, intake structures, gates, transitions, and the conduit itself.

143. The above equation is incorporated into RESOUT. The discharge coefficient (K) for friction losses in the conduit is computed by the program using either the Darcy-Weisbach or Manning equations. The total K for all other outlet structure components is provided as input data by the user.

144. The head (H) is the reservoir water surface elevation minus the water surface or zero pressure elevation in the exit portal. Figure 18 shows the results of laboratory tests made at the State University of Iowa relating the zero pressure elevation at the exit portal of a circular conduit to the Froude number for the flow in the conduit (USACE 1963).

145. The suggested design curve in Figure 18 is coded into RESOUT as a table which is read by linear interpolation. RESOUT computes the Froude number for a given discharge and conduit diameter. The elevation of the zero pressure point above the invert of the exit portal is determined from the relationship shown in Figure 18. The head (H) is computed as the difference in reservoir water surface elevation and exit portal zero pressure elevation. Alternatively, a discharge versus water surface (or zero pressure) elevation relationship can be provided as user-specified input data.

Partly open gate control

146. When conduits are operated under head with gates partly open, pressure flow occurs upstream from the gate and if tailwater level permits, open channel flow occurs downstream from the gate. The discharge control is located at the gate. The equation

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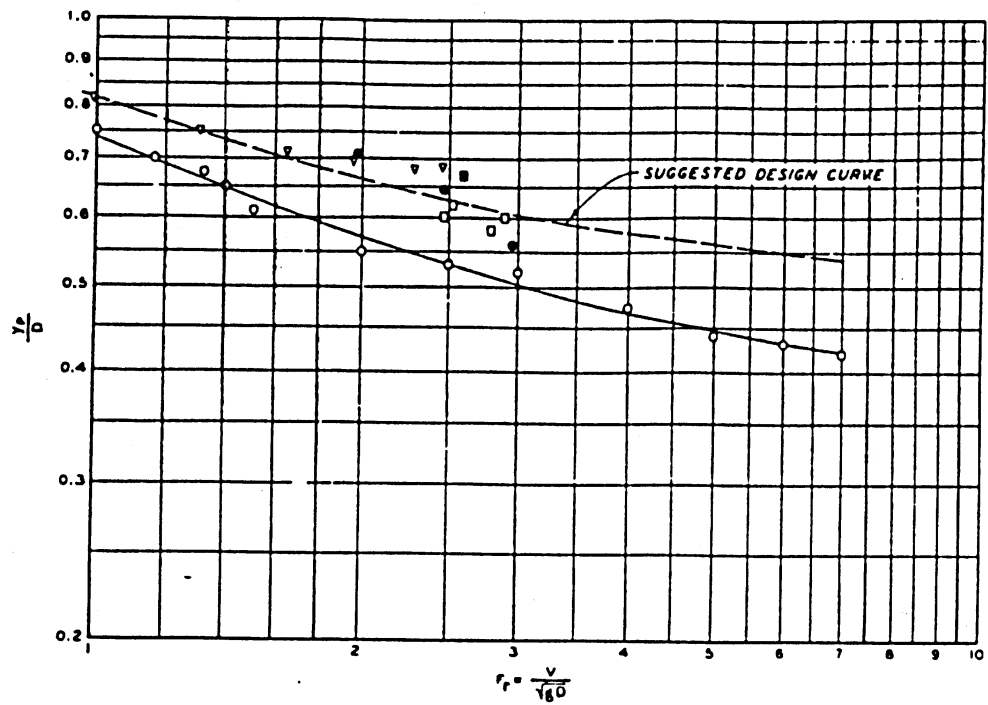
LEGEND

SYMBOL	DATA SOURCE	BOTTOM SUPPORT
o	STATE UNIVERSITY OF IOWA	NONE
□	DENISON MODEL	LEVEL
■	DENISON PROTOTYPE	LEVEL
●	GARRISON MODEL	PARABOLIC
▼	YOUGHIOGHENY MODEL	I ON 20
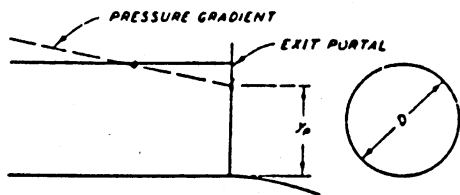
**EXIT PORTAL PRESSURE
CIRCULAR CONDUITS**

Figure 18.   Exit portal pressure (after EM 1110-2-1602
(USACE 1963) Plate 3)

$$Q = A (2gH/K)^{0.5} \qquad (40)$$

is applicable to partly opened gates. A is the area of the gate opening. The loss coefficient K includes the gate loss and contraction coefficients in addition to coefficients for the other losses, such as entrance and friction, which occur upstream of the gate. All loss coefficients should be expressed as coefficients of the velocity head at the gate opening.

147. In cases such as this, in which velocity head varies between locations in the conduit, equivalent K values can be determined based on the continuity equation.

Since

$$Q = V_1 A_1 = V_2 A_2 \qquad (41)$$

then

$$V_2 = (A_1/A_2)V_1 \qquad (42)$$

and

$$V_2^2 = (A_1/A_2)^2 V_1^2 \qquad (43)$$

Therefore, the loss coefficient (K) at location 1 can be expressed as a coefficient of the velocity head at location 2 by multiplying K by $(A_1/A_2)^2$.

Conduit friction losses

148. Head losses in a straight length of conduit can be estimated with a number of alternative empirical formulas, such as the Darcy-Weisbach, Manning, Hazen-Williams, and Scobey equations. The Darcy-Weisbach and Manning equations are incorporated as options in the RESOUT computer program.

149. Manning equation. The Manning equation can be expressed as

$$h_f = (\phi n^2 L/R^{4/3})(V^2/2g) \qquad (44)$$

for which the head loss coefficient (k_f) becomes

$$k_f = \phi n^2 L / R^{4/3} \qquad\qquad (45)$$

The ϕ includes the 2g term and the conversion factor from English to metric units. The value of ϕ is 19.62 when metric units are used and 29.1 for English units. Ranges of values for the Manning roughness coefficient (n) for various types of outlet conduits are presented by the USBR (1977) and reproduced here as Table 2. Measured n values at several USACE dams are cited in Table 3 (USACE 1965).

150. <u>Darcy-Weisbach equation.</u> The head loss resulting from pipe friction may also be determined using the Darcy-Weisbach equation

$$h_f = f(L/D)(V^2/2g) \qquad\qquad (46)$$

151. The friction factor (f) is a function of the relative roughness (e/D) of the pipe and the Reynolds number (R_e) of the flow.

$$R_e = DV/v \qquad\qquad (47)$$

where v is the kinematic viscosity, which is 0.000001003 m²/sec for water at a temperature of 20° C. If R_e is less than 2,100, the flow is laminar. The flow is turbulent for R_e over 3,000. Between these values, a transitional type of flow exists. The relative roughness (e/D) of a pipe depends on the absolute effective roughness (e) of the interior surface and the diameter (D). A hydraulically smooth pipe is a flow condition in which the wall roughness is completely covered by a laminar boundary layer. For a given Reynolds number, the smooth pipe curve in the Moody diagram is the lower limit for the value of the friction factor (f). The Moody diagram reproduced in Figures 19 and 20 illustrates the various flow regions. Measured data from a number of USACE projects are plotted on Figures 19 and 20, respectively, for concrete and steel conduits (USACE 1965).

152. The Moody diagram is coded in the RESOUT computer program in the form of the equations for smooth pipe, fully rough, and transitional flow conditions. The von Karman and Prandtl equation for smooth pipe flow is
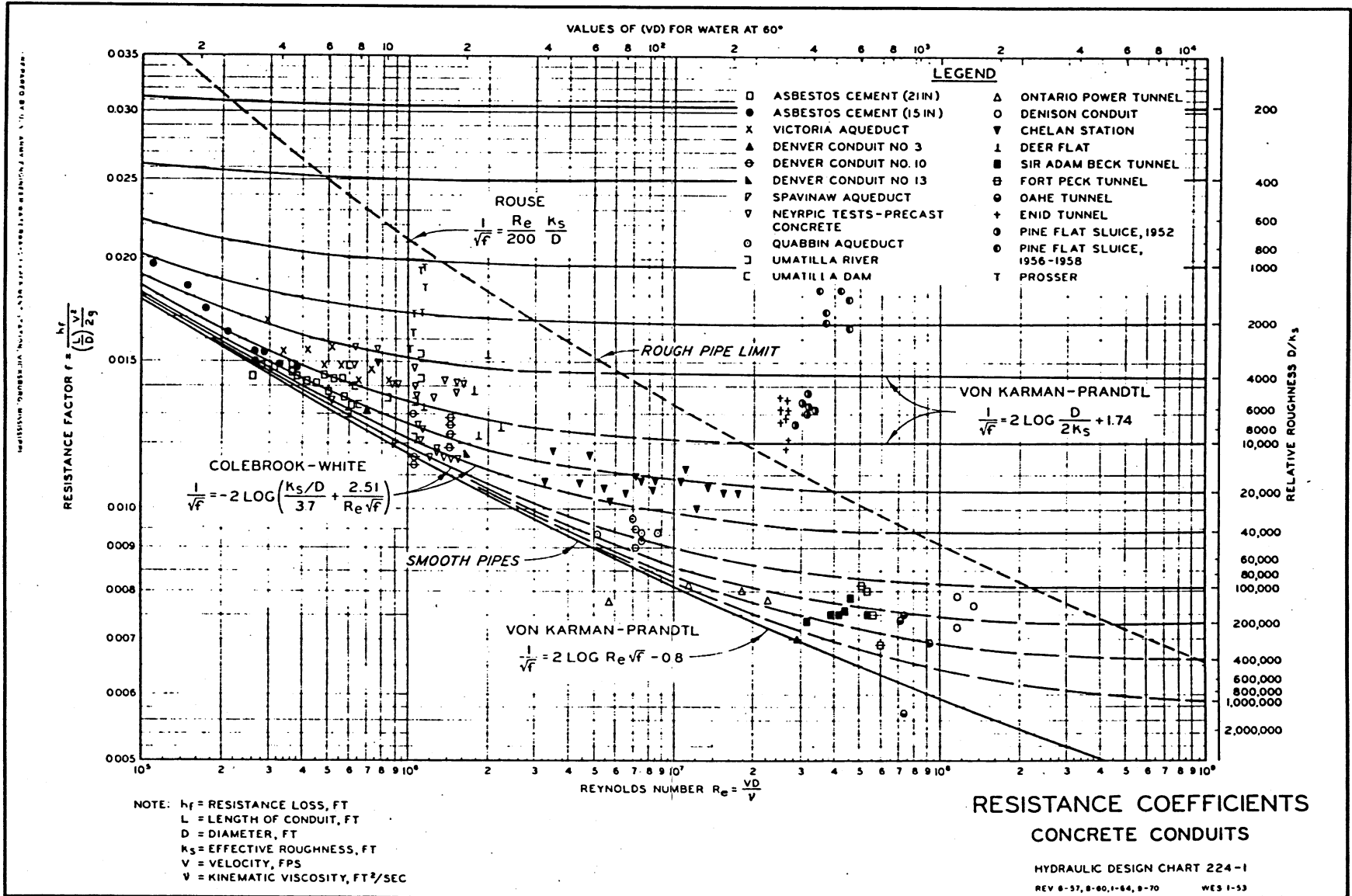
Figure 19. Moody diagram with plotted data from concrete conduits
(after HDC 224-1 (USACE 1988))
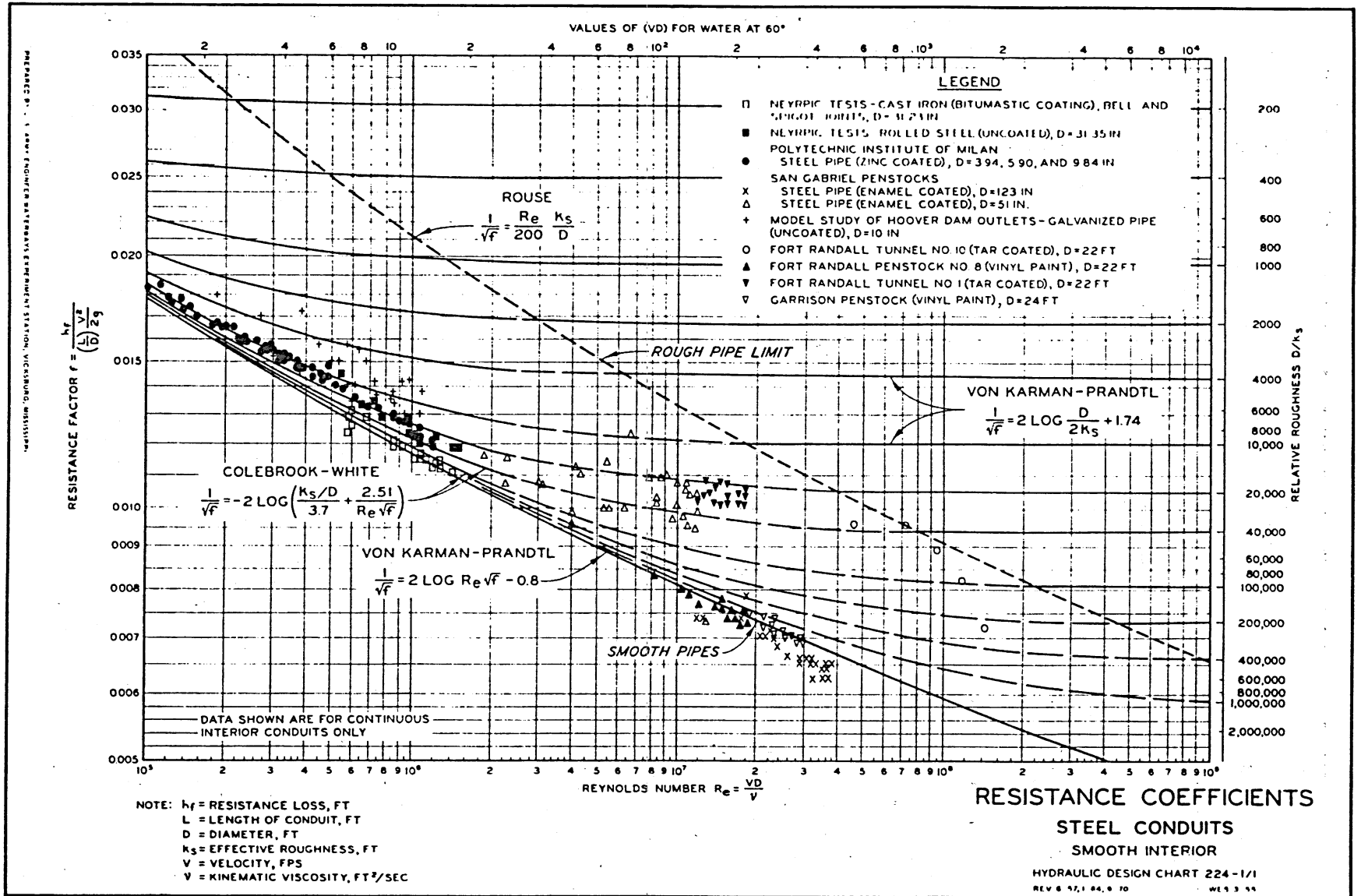
Figure 20. Moody diagram with plotted data from steel conduits
(after HDC 224-1/1 (USACE 1988))

$$1/(f)^{0.5} = 2 \, Log \, R_e(f)^{0.5} - 0.8 \qquad (48)$$

The friction factor (f) for smooth pipe flow is a function of only the Reynolds number (R_e).

153. The von Karman-Prandtl rough pipe equation is

$$1/(f)^{0.5} = -2 \, Log \, (D/2e) + 1.74 \qquad (49)$$

Rough pipe is a function of relative roughness (e/D), but is independent of the Reynolds number.

154. The lower limit of the rough flow zone is defined as follows:

$$1/(f)^{0.5} = (R_e e)/(200D) \qquad (50)$$

155. The area of the Moody diagram between the smooth pipe curve and the rough flow limit is a transition region. The Colebrook and White equation for transition flow

$$1/(f)^{0.5} = -2 \, Log \, (e/3.7D) + [2.51/R_e(f)^{0.5}] \qquad (51)$$

includes both Reynolds number and relative roughness.

156. RESOUT computes the frictional head loss in a conduit using the Darcy-Weisbach equation with conduit length (L), diameter (D), and absolute roughness (e) and the kinematic viscosity (v) of the water specified by the user as input data. Effective roughness (e) values for various types of conduits are shown in Table 4.

Noncircular conduits

157. The Darcy-Weisbach equation is expressed in terms of conduit diameter. The Manning equation is also coded in RESOUT based on a user-supplied conduit diameter. Thus, the frictional head loss computations assume the conduit has a circular cross section. However, the head loss in a noncircular conduit can be assumed to be the same as the head loss in a circular conduit

Table 4

Conduit Roughness Coefficient

Type of Conduit	Diameter (feet)	Roughness (e) (feet)
Concrete		
Asbestos cement pipe under	2.0	0.0003
Pre-cast concrete pipe under	5.0	0.0010
Circular concrete conduits	-	0.0020
Rectangular concrete conduits	-	0.0030
Steel		
Tar-dipped under	1.0	0.0001
Tar-coated	1 to 5	0.0003
Tar-brushed	over 5	0.0020
Asphalt	under 6	0.0010
Asphalt-brushed	over 6	0.0010
Vinyl or enamel paint	all	0.0100
Galvanized, zinc-coated	all	0.0006

Source: HDC 224-1 and 224-1/1 (USACE 1988)

having an equivalent hydraulic radius (Cox 1973). The equivalent diameter (D) is computed as

$$D = 4R = 4(A/WP) \qquad (52)$$

where R is the hydraulic radius of the noncircular conduit which equals the cross-sectional area (A) divided by the wetted perimeter (WP). Hydraulic radius formulas for various common conduit shapes are presented in Figure 21.
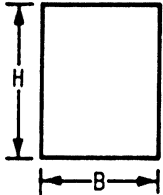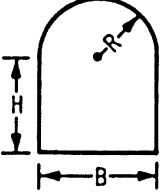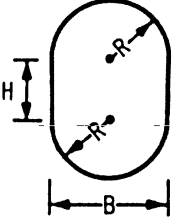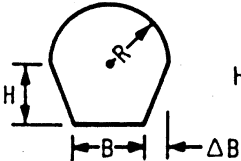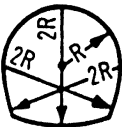
Other head losses

158. The total head loss coefficient (K) is the summation of the loss coefficients (k_i) for each structure component which produces a head loss. In addition to losses due to conduit friction, head losses are caused by trash-racks, entrance curves, bulkhead and gate slots, transitions, piers, exit contractions, deflectors, and the exit. Partially open gates and valves control the discharge rate by causing a head loss.

159. In applying RESOUT, the user inputs a single K value which is the summation of all component loss coefficients, with the exception of the coefficient for conduit losses which can be computed by the model using the Darcy-Weisbach or Manning equations. Thus, the loss coefficient values k_i, other than for conduit friction, are estimated and totalled independently of RESOUT, and the total K is provided as input to the computer program.

160. Engineering judgment is required to estimate loss coefficient values for the particular reservoir for which a rating curve is being developed. Empirical loss coefficient data for various outlet structure components are presented by WES (USACE 1963, 1965), and USBR (1977). Selected data are reproduced here. The loss coefficients discussed below are applicable to the velocity head in conduits under pressure flow conditions with the entrance submerged. Loss coefficients for open channel flow are typically significantly higher than for pressure conduit flow.

161. Trashrack loss. Head loss coefficients for trashracks depend upon the bar thickness, bar shape, and spacing. Loss coefficients are provided in Figure 22 as a function of the ratio (A_r) of the area of bars to area of section for alternative trashrack designs. This data should provide conservatively high values for unclogged trashracks. However, the values may be increased in applications involving significant accumulation of debris on the trashrack. Trash structures which consist of widely spaced structural members

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SECTION	AREA (A)	WETTED PERIMETER (WP)	HYDRAULIC RADIUS (R)
[Rectangle, H × B]	BH	$2(B+H)$	$\dfrac{BH}{2(B+H)}$
[Circle, D]	$\dfrac{\pi D^2}{4}$	πD	$\dfrac{D}{4}$
[Arch, H, B, R]	$BH + \dfrac{\pi R^2}{2}$	$B + 2H + \pi R$	$\dfrac{BH + \dfrac{\pi R^2}{2}}{B + 2H + \pi R}$
[Oblong, H, B, R]	$BH + \pi R^2$	$2(H + \pi R)$	$\dfrac{BH + \pi R^2}{2(H + \pi R)}$
[Shape, H, B, ΔB, R]	$H(B + \Delta B) + \dfrac{\pi R^2}{2}$	$B + 2(H^2 + (\Delta B)^2)^{1/2} + \pi R$	$\dfrac{H(B + \Delta B) + \dfrac{\pi R^2}{2}}{B + 2(H^2 + (\Delta B)^2)^{1/2} + \pi R}$
[Horseshoe, 2R, R]	$3.3172\,R^2$	$6.5338\,R$	$0.5077\,R$

HYDRAULIC ELEMENTS

CONDUIT SECTIONS

PRESSURE FLOW

HYDRAULIC DESIGN CHART 224-2

WES 5-75

Figure 21. Hydraulic elements for conduit sections (after HDC 224-2 (USACE 1988))
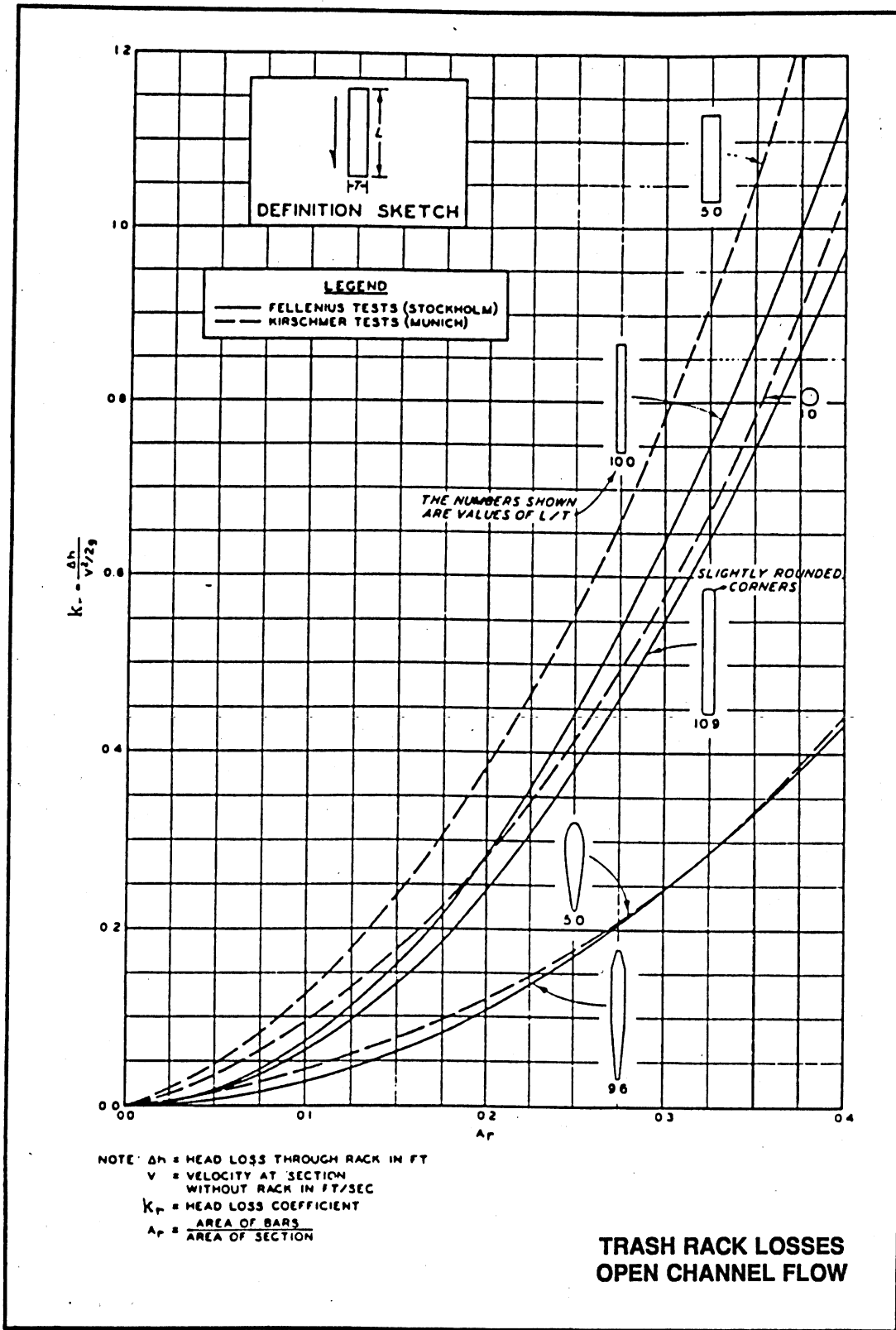
Figure 22.   Loss coefficient for trashracks (after EM 1110-2-1602
(USACE 1963) Plate 5)

without rack bars will cause very little head loss, and a loss coefficient in the range of 0-0.02 might be used.

162. <u>Intake structure loss.</u> The intake structure loss coefficient values shown in Table 5 were compiled by the USBR (1977) from various sources. The results of USACE (1963) analyses of prototype and model data for several projects are presented in Figure 23. The USACE coefficients represent the entire intake structure including the entrance, gate slots, and transition. For just gate slots, a loss coefficient of 0.01 is suggested for each pair of gate slots. A loss coefficient of 0.05 is suggested for a pier with rounded ends.

163. <u>Bend loss.</u> The bend loss, in addition to conduit friction loss, is a function of bend radius, pipe diameter, and deflection angle of the bend. Curves showing bend loss coefficients are reproduced as Figure 24. The curves are applicable to circular conduits and to rectangular conduits for which the width-height ratio does not vary greatly from unity, in which case D is taken equal to the conduit height for vertical bends and the conduit width for horizontal bends.

164. <u>Exit constriction loss.</u> In computing discharge through a conduit which contains an exit constriction, all losses should be expressed in terms of the velocity head corresponding to the smallest cross-sectional area of the constriction and that area used in the basic discharge-head equation. Conduit losses expressed in terms of velocity head corresponding to the cross-sectional area of the conduit at the point where the loss occurs may be converted to terms of the velocity head corresponding to the smallest constriction area. The former loss coefficients are multiplied by a factor A_2^2/A_1^2, where A_1 and A_2 are the areas of the conduit at the point of loss occurrence and at the constriction, respectively.

165. <u>Exit velocity head.</u> A loss coefficient of 1.0 is used to represent the velocity head at the exit.

<center>Breach Simulation</center>

166. In addition to using outlet structures, reservoir releases during military operations can be achieved by breaching the dam. A portion of a dam may be destroyed by explosives or other means. Dam breaches can also be caused by the reservoir level overtopping the dam. In certain situations, outlet structure gates may be closed and/or openings otherwise blocked to

Table 5

Entrance Loss Coefficient

Entrance Description	Loss Coefficient		
	Maximum	Minimum	Average
Gate in thin wall, unsuppressed contraction	1.80	1.00	1.50
Gate in thin wall, bottom and sides suppressed	1.20	0.50	1.00
Gate in thin wall, corners rounded	1.00	0.10	0.50
Square-cornered entrances	0.70	0.40	0.50
Slightly rounded entrances	0.60	0.18	0.23
Fully rounded entrances	0.27	0.08	0.10
Circular bellmouth entrances	0.10	0.04	0.05
Square bellmouth entrances	0.20	0.07	0.16
Inward-projecting entrances	0.93	0.56	0.80

Source: USBR (1977)

SHAPE	PROJECT [1]	CONDUIT PROPER LENGTH/DIAM [2]	REYNOLDS NUMBER [2]	VELOCITY HEAD [1]	AVERAGE INTAKE COEFFICIENT K_e
	SINGLE INTAKE (CONCRETE DAM CONDUITS)				
PROFILE	PINE FLAT (PROTOTYPE) A=90, B=30 C=90, E=50 F=50, G=17	54	29-36 x 10⁷ (PROTOTYPE)	65-81	0 16
PLAN	CW 802 (1 20 MODEL) A=7 5, B=2 5 C=10 0, E=5 7 F=4.3, G=1.4	83	6 7 x 10⁶ (MODEL)	97	0 07 [3]
	DOUBLE INTAKE (EARTH DAM TUNNEL)				
PROFILE (4)	DENISON (PROTOTYPE) A=250, B=390 C=190, D=200 E=90, T=53.0	40	1 2 x 10⁸ (PROTOTYPE)	66	0 19
	DENISON (1 25 MODEL) (SEE ABOVE)	47	8 2-9 6 x 10⁶ (MODEL)	61-82	0 12
PLAN	FT RANDALL (5) (PROTOTYPE) A=240, B=16 0 C=23 0, D=22 0 E=11.0, T=490	39	0.7-1.5x10⁶ (PROTOTYPE)	16 - 72	0.25
	FT RANDALL (1 25 MODEL) (SEE ABOVE)	39	0 9-1 0 x 10⁶ (MODEL)	46-86	0 16
	TRIPLE INTAKE (EARTH DAM TUNNEL)				
PROFILE / PLAN	TIONESTA (1 36 MODEL) A=300, B=220 C=160, D=190 E=7 5, T=66.0	98	1 5-41x10⁵ (MODEL)	7-50	0 33

INTAKE HEAD LOSS:

$$h_L = k_e \frac{V^2}{2g}$$

V = VELOCITY IN CONDUIT PROPER

(1) DIMENSIONS IN PROTOTYPE FEET
(2) EQUIVALENT DIAMETER FOR NON-CIRCULAR SECTIONS BASED ON HYDRAULIC RADIUS
(3) DOES NOT INCLUDE GATE SLOT LOSSES
(4) LENGTH OF TRANSITION
(5) ROOF CURVE MAJOR AXIS HORIZONTAL

INTAKE LOSSES

Figure 23. Loss coefficient for intake structures (after
EM 1110-2-1602 (USACE 1963) Plate 6)
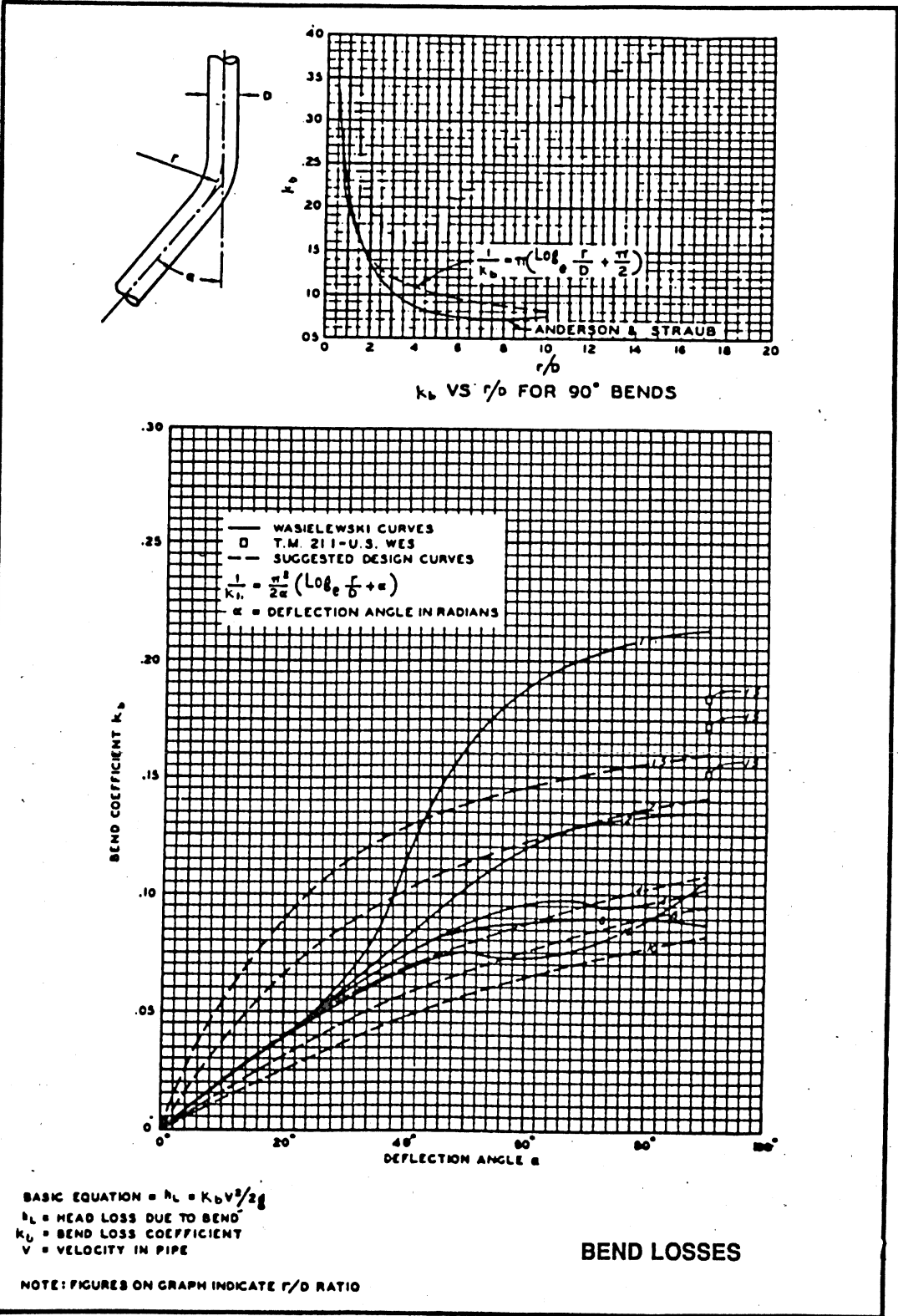
Figure 24. Loss coefficient for bends (after EM 1110-2-1602 (USACE 1963) Plate 7)

cause inflows to fill the reservoir and overtop the dam, resulting in a breach.

167. Breach characteristics depend upon numerous factors, including the configuration and materials of the dam; reservoir depth, volume, and inflow; and the situation or action that caused the dam failure. Different breach characteristics are generally associated with various types of dams.

168. Earthen embankments are the most common type of dam. Erosion of a breach through an earthen dam may be relatively slow at first, accelerating as flow velocities increase, and then decreasing again as the tailwater increases. Flow overtopping the embankment will probably first erode the downstream face of the dam, particularly near the dam toe where velocities are greatest. The breach will grow upstream from the dam toe, as well as downward from the top of the dam and laterally outward. The erosion may be gradual for periods of time and then accelerate, as portions of the embankment collapse into the breach. An entire embankment could fail, but most likely the breach will affect only a portion of the structure.

169. Concrete gravity dams are characteristically stable and may collapse only in the section that is overstressed. One or several monoliths may break away and be pushed downstream while the remainder of the dam remains in place. Slab and multiple-arch buttress dams may disintegrate as the buttresses fail in succession. Single-arch dams may collapse almost instantaneously and completely. A dam with water ponded behind a large release structure, such as a spillway with multiple tainter gates, could be effectively "breached" by destroying the gates or simply opening the gates very rapidly.

170. Prediction of breach characteristics is difficult. The RESOUT model includes a modified version of a breach routine previously incorporated in the DAMBRK (Fread 1984) and HEC-1 (US Army Engineer Hydrologic Engineering Center 1985) computer programs. With this approach, the model does not provide assistance to the user in determining the breach characteristics which would result from a given action or situation. However, the breach simulation routine does provide a generalized, easy-to-use computational framework consistent with present capabilities for estimating breach parameters (Wurbs 1985).

171. As illustrated in Figure 25, the breach is represented by a trapezoidal-shaped weir with dimensions that grow linearly with time. A zero side slope results in a rectangular breach. A zero bottom width means a triangular breach. The following user-specified input data are required:

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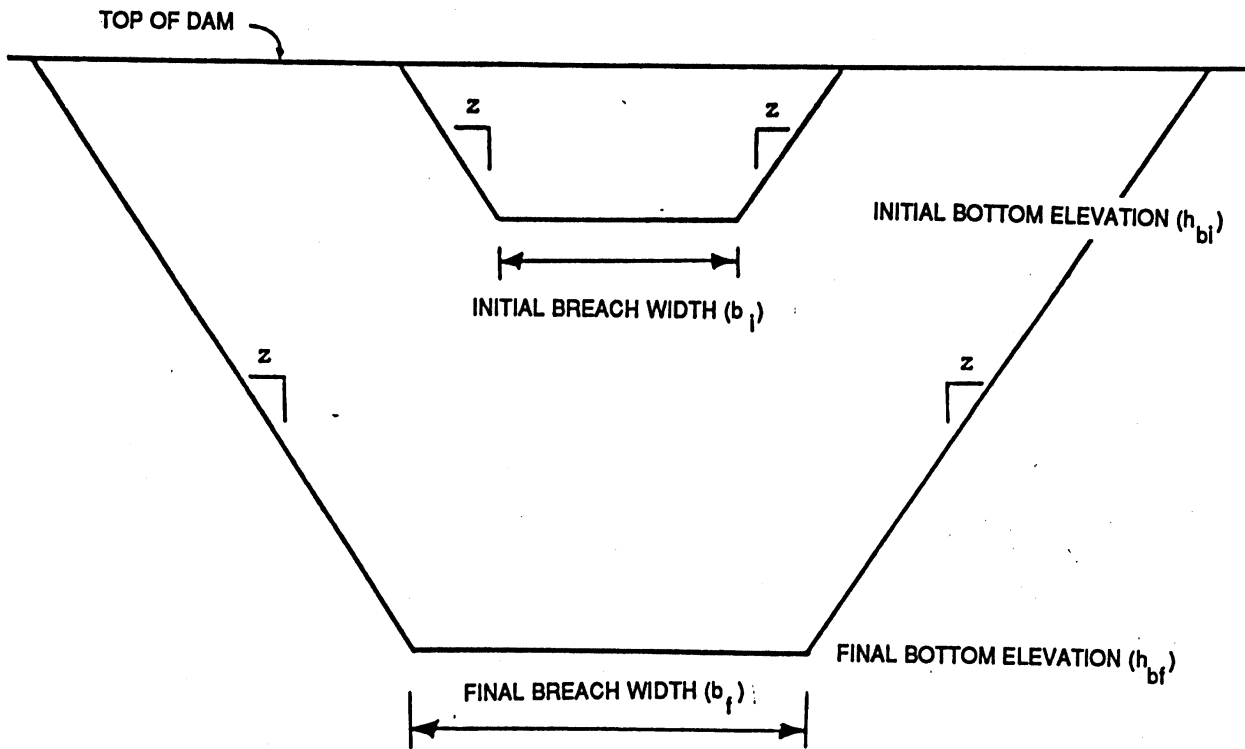
Figure 25. Breach simulation

(a) initial and final breach width (b_i and b_f) and bottom elevation (h_{bi} and h_{bf}); (b) breach side slopes (z); (c) reservoir water surface elevation which initiates the breach; and (d) time (t_b) for the breach to form.

172. The breach simulation is used in conjunction with reservoir routing. At the beginning of the routing computations, the breach is represented as a weir with the user-specified initial breach width (b_i) and bottom elevation (h_{bi}). The b_i and h_{bi} may be zero and the top of dam elevation, respectively, indicating no breach has yet formed at the beginning of the computations. The breach grows outward and downward beginning when the reservoir water surface first equals or exceeds the user-specified value. The width (B) and bottom elevation (h_b) grow linearly over the breach time (t_b) until the final breach width (b_f) and elevation (h_{bf}) are reached.

173. The weir equation with approach velocity and submergence corrections, as previously presented in conjunction with broad-crested spillway rating curves, is used to compute the discharge through the breach at each time step. However, unlike a spillway, the breach width and crest elevation can change as a function of time. Consequently, the breach does not have a unique

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rating curve. The weir discharge computations are performed simultaneously with the routing computations.

174. The weir equation is written as follows.

$$Q = k_v k_s (C_r B H^{1.5} + C_t H^{2.5})$$ (53)

where

$k_v = 1.0 + 0.023 Q^2 / [W^2 (h-h_f)^2 (h-h_b)]$

$k_s = 1.0$ if $(h_t-h_b)/(h-h_b) = 0.67$

$k_s = 1.0 - 27.8 [(h_t-h_b)/(h-h_b)] - 0.67)^3$ otherwise

$B = b_f$ if $t-t_o = t_b$

$B = b_i + (b_f-b_i)(t-t_o)/(t_b-t_o)$ otherwise

$h_b = h_{bf}$ if $t-t_o = t_b$

$h_b = h_{bi} - (h_{bi}-h_{bf})(t-t_o)/(t_b-t_o)$ otherwise

$H = h - h_b$

The approach velocity and submergence correction factors are denoted by k_v and k_s, respectively. C_r and C_t denote discharge coefficients for the rectangular and triangular portions of the trapezoidal weir. C_r and C_t are userspecified, with default values of 3.1 and 2.45 coded in RESOUT. B is the width of the rectangular portion of the weir at time t, and z is the breach side slope. At any time (t), the reservoir water surface, breach bottom, and tailwater elevations are h, h_b, and h_t, respectively. The initial and final elevations of the breach bottom are denoted h_{bi} and h_{bf}. The initial and final breach widths are b_i and b_f, respectively. The breach begins to grow at time t_o.

Storage Routing

175. Reservoir routing consists of computing outflow as a function of time, using the continuity equation

$$(I_1 + I_2)/2 - (O_1 + O_2)/2 = (S_2 - S_1)/ t$$ (54)

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where I, O, and S denote inflow, outflow, and storage, respectively. The sub-scripts 1 and 2 refer to the beginning and end of a computational interval t. At each time step, O_2 and S_2 are unknown. Values for O_1 and S_1 are known from the computations for the previous time step. Values for I_1 and I_2 are obtained from a known inflow hydrograph. A single-value relationship is assumed to exist between storage and outflow. Reservoir water surface elevation versus outflow and storage relationships are combined to obtain a storage-versus-outflow relationship.

176. RESOUT contains two reservoir storage routing options. Both are based on the continuity equation. One is an iterative and the other a non-iterative solution of the continuity equation. The modified Puls method is a noniterative solution algorithm which requires a rating curve as input. When using this option in RESOUT, rating curves are computed for the various outlet structures and combined prior to the routing computations. The computed com-bined rating curve then becomes input for the routing routine. However, if a dam breach is included in the analysis, an iterative solution of the contin-uity equation is required because the water surface elevation versus discharge relationship varies with time. Consequently, a second routing option is used for computing an outflow hydrograph involving a dam breach. Rating curves for other outlet structures can also be included. Inclusion of reservoir evapora-tion also requires an iterative solution. Thus, the iterative solution of the continuity equation option must be used if a dam breach or reservoir evapora-tion is included in the routing. Otherwise, modified Puls routing can be used.

Modified Puls routing

177. The modified Puls or storage indication method of storage routing is based on rearranging the continuity equation as follows:

$$2S_2/t + O_2 = I_1 + I_2 + 2s_1/t + O_1 \tag{55}$$

where at each computational time step, the right-hand side of the equation is known. The left-hand side is termed the storage indication. The storage indication is computed for each time step using the above equation. Outflow is determined from a relationship between $(2S/t + O)$ and outflow. The method is described by Viessman, Knapp, Lewis, and Harbaugh (1977) and Linsley and Franzini (1979).

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178. An elevation-versus-storage relationship and elevation-versus-outflow relationship are combined to develop an elevation-versus-outflow relationship. The storage indication relationship (2S/ t + O versus O) is developed from the storage-versus-outflow relationship. The modified Puls method can be used whenever a rating curve is available. In applying RESOUT, the rating curve may be computed or provided as input data by the user.

Iterative solution
of continuity equation

179. In the case of a dam breach simulation, the discharge-versus-elevation relationship varies with time as the breach grows. At each step of the routing computations, the outflow and storage must be determined iteratively. For an assumed end-of-period storage and corresponding water surface elevation, the outflow is computed using the weir equation. The computed outflow is then used to revise the storage estimate.

180. Reservoir evaporation can also be included in this routing option. Beginning and end-of-period storages are averaged to obtain an average storage during the computational interval t. The storage is then combined with a user-supplied reservoir elevation versus surface area relationship to determine an average surface area during the period. Evaporation is computed by multiplying the water surface area by an evaporation rate, which is specified by the user as input data.

Reservoir drawdown analysis

181. Military applications of the RESOUT model could involve the drawdown or emptying of a reservoir. For example, reservoir releases may be used to induce flooding or create barriers during combat operations. The reservoir itself may provide an obstacle to combat operations above the dam. Another example is the situation in which a strategically located dam is potentially subject to enemy attack directed at destroying the dam to induce downstream flooding. Drawdown plans could be developed for partially or completely emptying the reservoir whenever a significant threat of attack is considered to exist.

182. The reservoir routing capabilities of RESOUT can be used to perform drawdown analyses for various applications. Reservoir storage levels and discharges are computed as a function of time for a given operating plan. An operating plan is specified by the user as an outlet capacity rating curve and target outflow hydrograph. Release targets, as specified by the user-supplied target outflow hydrograph, are made at each time step of the routing unless

constrained by the outlet capacity or availability of water. Input data for the routing computations include an inflow hydrograph, outlet capacity rating curve, target outflow hydrograph, initial reservoir storage level, evaporation rate, and reservoir storage-versus-elevation relationship.

PART V: RESERVOIR OUTFLOW (RESOUT) COMPUTER PROGRAM DESCRIPTION

183.   The reservoir outflow (RESOUT) microcomputer model is a general-
ized software package for developing outlet structure rating curves and per-
forming storage routing computations. The procedures incorporated in the
program are outlined in Part IV of this report. Input data instructions,
example problems, definition of variables, and a program listing are provided
in Appendixes A, B, C, and D, respectively. A general description of the
program is provided below.

Summary of Program Capabilities

184.   RESOUT is a flexible package with a number of options which can be
used as needed depending on the application. Rating curves (reservoir water
surface elevation-versus-discharge relationships) can be developed for a com-
prehensive range of outlet structure types and configurations. Storage rout-
ing computations can be performed to determine an outflow hydrograph
(discharge-versus-time relationship). A rating curve for the outlet struc-
tures is part of the input data required for the reservoir routing computa-
tions. Discharge through a dam breach, with breach dimensions which increase
linearly over time, can be included in the routing. Reservoir evaporation can
also be included. A drawdown analysis can be performed for a given operating
plan, which is specified by an outlet capacity rating curve and target outflow
hydrograph.

185.   RESOUT develops rating curves using basic weir and orifice
equations. The rating curve computations are organized by outlet structure
category as follows: (a) uncontrolled ogee spillway; (b) uncontrolled broad-
crested spillway; (c) two alternative approaches for modeling gated spillways;
(d) drop inlet spillways; and, (e) outlet works. Since the computations are
based on fundamental equations representing the hydraulics of weirs and
orifices, the procedures are adaptable to the full spectrum of outlet struc-
ture types and designs. Rating curves for several outlet structures and/or
gate openings can be computed in a single run of the model for a single
reservoir.

186.   Discharge coefficients and other empirical data presented in
Part IV are coded into the model, for the convenience of the user.

Alternatively, values for the required coefficients can be provided by the user as input data.

187. RESOUT contains two reservoir routing routines. The modified Puls method is a noniterative solution of the continuity equation. The second option is an iterative solution of the continuity equation. RESOUT uses the modified Puls approach unless a dam breach, reservoir evaporation, and/or target outflow hydrograph are included in the simulation, in which case an iterative solution is required.

Program Structure

188. RESOUT is a batch-oriented program written in ANSI standard FORTRAN 77 to execute in a 640K, IBM-compatible microcomputer. It is composed of a main driver program and a series of subroutines that may be called by the main program or from other subroutines. The subroutines are listed in Table 6. The array sizes are set to a maximum of 100 due to memory restrictions. The variable names are, in most cases, set to the maximum of six characters to be most descriptive of the value they represent.

Input data

189. The inputs to the program are on multi-valued records. These records are generated using any standard line editor. Their general format is two capitalized alphanumeric characters followed by up to 10 fields of data. The data cannot extend past column 80 in the input record, and there must be at least one blank space between individual values. The majority of these records are input using the RDIN subroutine.

190. If the record sequence is in error, execution is terminated, and an error message is printed through subroutine ERR. This output will also list the ID of the record in error. No error checking of the actual input values is done.

Header information

191. The main body of the program first inputs the names of the files to be used. The names of these files are limited to eight characters to be in agreement with standard MS-DOS practice. Any characters in excess of this will be truncated. The program will then verify that the requested files exist and create the output file, if required.

Table 6

Subroutines

BREACH   Routes a hydrograph through a reservoir using an iterative solu-
            tion of the continuity equation. Breach simulation and reservoir
            evaporation algorithms are included.

CHANIN   Used to input the downstream channel geometry as elevation versus
            top width or rating curve as elevation versus discharge.

DATINT   Block data subroutine used to initialize the curves of coeffi-
            cients in the program.

DBLINT   Performs a double linear interpolation of input values.

DRPINL   Computes the rating curve for a drop inlet spillway.

ERR   Called when a record is found to be out of sequence. The record
            ID is listed, and program execution is terminated.

INTERP   Performs a linear interpolation of input values.

LISTOT   Echoes the input file to the output file.

OTFLW   The driving subroutine for the outlet structure rating curve
            computations. It is called by the main program and calls each of
            the rating curve subroutines as required.

OTWRKS   Computes the rating curve for an outlet works.

OUTPUT   Outputs the results of the previously computed rating curves
            and/or routing hydrographs.

PULS   Routes a hydrograph through a reservoir using the modified Puls
            method.

RDIN   Reads the data from the input record and converts it to a numeric
            value in the array TARA.

SVOL   Converts reservoir surface area versus elevation to reservoir
            storage versus elevation if surface area is input.

TAINGT   Computes the rating curve for a tainter gate. It allows up to
            10 gate openings and three different sets of gates.

TITEPT   Prints the title to the screen or to the output file.

TWATER   Computes the depth of water in a channel from a given flow rate
            using Manning's equation or a given elevation-versus-discharge
            relationship.

UNBDCR   Computes the rating curve for an uncontrolled broad-crested weir.

UNCNOG   Computes the rating curve for an uncontrolled ogee spillway.

VLIFTG   Computes the rating curve for a vertical lift gate. It allows up
          to 10 gate openings and three different sets of gates.

192. The program will then read in three ID records. The labels on these records are limited to 78 characters. These records are for user identification of the output only.

193. An IO record is next read to determine if the input data are to be echoed to the output file. If they are, subroutine LISTOT is called, and the input file is listed out.

194. A KK record is the next input. The information provided on this field is limited to 40 characters and is echoed out as the reservoir name in the output.

Rating curve generation

195. The downstream channel geometry or rating curve is next input through the use of the subroutine CHANIN. From the elevation-versus-top width or elevation-versus-discharge information provided as input data, the depth of flow in the downstream channel is calculated by subroutine TWATER for use in the submergence computations in subroutines UNBDCR and UNCNOG. With the elevation-versus-top width input option, the Manning equation is used in subroutine TWATER for the computation of flow depth.

196. The next section of the program calculates the rating curves by calling the subroutine OTFLW. At least one structure must be specified. If no outflow is desired, a rating curve with a zero outflow for all elevations may be used. The subroutines for the different types of outlet structures specified by the user are called as needed. The final result from this section is one combined rating curve that is used in the routing section of the program.

197. The user may, at this point, terminate the program by the insertion of a ZZ record. The output generated will be the series of rating curves requested by the user, and no routing will be done.

Routing

198. If routing is required, reservoir storage data are next inputted to the program. Reservoir water surface elevation versus either storage or water surface area are entered. If the latter is chosen, subroutine SVOL computes reservoir storage volume from the given surface areas. The elevation included in the inputted storage or area data must encompass the elevations given as minimum and maximum for the computation of rating curves.

199. The starting reservoir water surface elevation and the inflow hydrograph are provided as input data. A maximum of 99 discharges may be entered from the inflow hydrograph records.

200. Routing is performed with either subroutine PULS or subroutine BREACH, depending on whether the continuity equation can be solved by the noniterative modified Puls approach. An iterative solution algorithm is required if a breach simulation or evaporation is included in the routing. The target release hydrograph option is also combined with the iterative solution method.

201. The standard modified Puls routing method is incorporated into subroutine PULS. The storage indication curve ($2S/\Delta t+O$ versus outflow) is developed. Using the inflow hydrograph and this relationship, an outflow is generated for each time step. Using the rating curve generated previously, the water surface elevation is also calculated.

202. An iterative solution of the continuity equation, which is incorporated in the BREACH subroutine, is used for performing a drawdown analysis with a specified target release hydrograph. For each time interval, the target release is made unless constrained by water available from storage and inflow or the outlet capacity rating curve. Reservoir evaporation can also be included in the analysis.

203. The BREACH subroutine also contains the breach simulation algorithm. The modified Puls method of routing is used until the reservoir water surface elevation reaches the user-specified elevation at which a breach will occur. Once this elevation has been reached, the outflow from the outlet structures is combined with flow through the breach to determine total outflow from the dam. The breach is characterized by the initial breach elevation and width, final elevation and width, side slope, and time from the start of the breach until the final width and elevation are reached. For each time step, the flow is divided between the rectangular and triangular sections of the breach. Any flow over the top of the dam is also considered as flow through a rectangular weir section. The bi-section method of convergence is used in the iterative solution algorithm.

204. The end result of each of the routings is an outflow hydrograph consisting of up to 99 discharges at the time intervals specified by the user. After the rating curves have been developed and the routing, if requested, is performed, the generated values are printed out. The output will include all rating curves and the outflow hydrograph.

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PART VI: SUMMARY AND RECOMMENDATIONS

205. Barrier creation resulting from the regulation of reservoir struc-
tures can inflict severe damage on military operations. Ferrying and bridging
operations can be completely halted by flood waves emanating from upstream
reservoirs. Pulsating flood waves can be propagated throughout downstream
river reaches by opening and closing the gated spillways. In a defensive sce-
nario, a potential deterrent to an attack on a strategically located dam could
be to partially empty the reservoir whenever a significant threat of attack is
considered to exist.

206. The ability to predict the extent of downstream flooding resulting
from reservoir regulation should be considered an important part of contin-
gency planning. This report provides the procedures necessary to make these
predictions.

207. Different types of dams, spillways, and outlet structures require
different computational procedures. This report identifies the various types
of structures that may make up a reservoir, and presents the basic hydraulic
equations for each. These computational procedures are then coded for an IBM
PC-compatible microcomputer. Input instructions and example applications are
also included. These applications include: (a) predicting reservoir outflow
for given conditions, (b) determining outlet structure gate openings or breach
size required to achieve specified outflows, and (c) analysis of reservoir
drawdowns.

208. The following recommendations are made, so that the procedures
developed may be useful to the military in the field:

> <u>a</u>. Procedures should be tested on specific reservoirs, and a com-
> parison made between predicted and actual discharge. These
> reservoirs would ideally be located outside of the US, since
> the equations in the procedures have been used in the design
> of most US structures.
>
> <u>b</u>. Sensitivity of the results to many of the required parameters
> should be determined in order to identify the most critical
> parameters.
>
> <u>c</u>. Procedures developed in this report should be linked to a
> routing capability, so that effects of reservoir regulation
> can be predicted at any point downstream. Likely candidates
> include: MILHY, TACDAM, and DAMBRK. By including these pro-
> cedures in MILHY, an inflow hydrograph to the reservoir could
> also be integrated. TACDAM and DAMBRK currently model only
> dam breaches, so the inclusion of the developed procedures
> would make these packages useful over a broader spectrum.

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APPENDIX A: INPUT DATA INSTRUCTIONS

RECORD	FIELD	FIELD CONTENTS

ID   Model Run ID Record (three records required)

    Col 1+2   ID

       1   Any label up to 78 characters long.

IO   Output Control Record (one required)

    Col 1+2   IO

       1   0 or blank   Do not echo input file to output file
       1   Echo input file to output file

       2   0   English units
            1   Metric units

KK   Reservoir Identifier (one required)

    Col 1+2   KK

       1   Any label up to 40 characters

RECORD   FIELD   FIELD CONTENTS

    C Records   Downstream Channel Records

  CG General Channel Geometry Record (one required)

      Col 1+2 CG

        1   Channel slope in feet/foot or metres/metre.

        2   Manning's roughness coefficient, n.

        3   1 The relationship to be entered is elevation
                  versus top width.

               2 The relationship to be entered is a rating
                  curve.

        4   The number of points to be entered as either a rating
              curve or elevation-versus-top width relationship
              (maximum of 20).

  CE   Channel Elevation Record (either CE and CT or EL and DC is
      required)

      Col 1+2 CE

      1 - 10   Elevations in feet or metres of the downstream channel as
            corresponding to the channel top widths given on the CT
            records. Ten fields per record only.

  CT   Channel Top Width Record (either CE and CT or EL and DC is
      required)

      Col 1+2 CT

      1 - 10   Top width of the downstream channel, in feet or metres,
            corresponding to the elevations given on the CE records.
            Ten fields per record only.

  EL   Elevation Record (either CE and CT or EL and DC is required)

      Col 1+2 EL

      1 - 10   Elevations, in feet or metres, for use in a downstream
            channel rating curve. Ten fields per record only.

DC   Discharge Record (either CE and CT or EL and DC is required)

        Col 1+2   DC

        1 - 10   Discharges, in cfs or m³/s, for use in a downstream channel rating curve. Ten fields per record only.

O Records   Outflow Structure Records
NOTE: At least one type of outflow structure must be chosen.

ON   General Outflow Information Record (one required)

        Col 1+2   ON

            1   The number of outflow structures to follow (maximum of five).

            2   Lowest elevation, in feet or metres, to be used in computation of rating curves (NOTE: this elevation must be below the crest of the spillway).

            3   Highest elevation, in feet or metres, to be used in the computation of rating curves.

            4   The number of points to generate in the rating curves between the highest and lowest elevations previously supplied (maximum of 99).

RECORD	FIELD	FIELD CONTENTS

UO   Uncontrolled Ogee Spillway
Two Records Required

Record 1
Col 1+2 UO

    1   Kp   +   Use the given pier contraction coefficient.

              0   Use no pier contraction coefficient.

              -    Use the internal tables to generate a pier contraction coefficient.

    2 Ka   +   Use the given abutment contraction coefficient.

              0   Use no abutment contraction coefficient.

              -    Use the internal tables to generate an abutment contraction coefficient.

    3 C   +   Use the given weir flow coefficient.

              0   Use the internal tables to generate a weir flow coefficient.

    4 Approach width, in feet or metres, of channel leading to ogee spillway.

    5 Approach depth, in feet or metres, of channel leading to ogee spillway.

    6 Height of crest, in feet or metres, above approach apron or approach channel.

    7 Design head, in feet or metres.

    8 Number of piers in the spillway.

    9 Net length, in feet or metres, of the spillway excluding the total width of included piers.

   10 Pier type of the included piers (1-4).

RECORD   FIELD   FIELD CONTENTS

Record 2

    Col 1+2   UO

      1   Elevation, in feet or metres, of the crest of the spillway.

      2   1 The material immediately adjacent to the spillway is concrete.

         2 The material immediately adjacent to the spillway is earth.

      3   The adjacent section radius, in feet or metres, if the material is concrete.

      4   Cs +   Use the given submergence coefficient.

          0   Make no correction for submergence.

          -    Use the internal tables to generate a submergence coefficient.

      5   Number of slope face correction factor pairs for non-vertical slopes that will appear on the following records (maximum of 99)

Record 3
    Col 1+2 UO

      1-10 Head, in feet or metres, over the spillway corresponding to the following slope face correction factors. Use as many records as required with 10 values per record.

Record 4
    Col 1+2 UO

      1-10 Slope face correction factors corresponding to the previous heads over the spillway.

UB   Uncontrolled Broadcrested Weir Record

Col 1+2   UB

1   C1   +   Use the entered coefficient for the rectangular section of the weir.

0   Use the default value (3.087) for the rectangular section of the weir.

2   C2   +   Use the entered coefficient for the triangular section of the weir.

0   Use the default value (2.45) for the triangular section of the weir.

3   Elevation, in feet or metres, of the crest of the spillway.

4   Overall width, in feet or metres, of the spillway crest.

5   Side slope of the spillway, in feet horizontal to 1 foot* vertical.

6   Width of the reservoir at the spillway.

7   Approach depth, in feet or metres, of channel leading to spillway.

8   Cs   +   Use the given submergence coefficient.

1   Make no correction for submergence.

-    Use the internal tables to generate a submergence coefficient.

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

RECORD	FIELD	FIELD CONTENTS

DI   Drop Inlet Record

     Col 1+2 DI

        1   Height of crest, in feet or metres, above surrounding surface.

        2   Radius of inlet, in feet or metres.

        3   C   +   Use the given weir flow coefficient.

        0   Use the internal tables to generate a weir flow coefficient.

        4   Elevation of the crest, in feet or metres.

EL   Elevation Record (If EL and DC are used, no other outlet structures can be used. The number of points must correspond to the value given in field 4 on the ON record.)

     Col 1+2 EL

     1 - 10 Elevations, in feet or metres. Ten fields per record only.

DC   Discharge Record (If EL and DC are used, no other outlet structures can be used. The number of points must correspond to the value given in field 4 on the ON record.)

     Col 1+2 DC

     1 - 10 Discharges in cfs or m^3/s. Ten fields per record only.

RECORD	FIELD	FIELD CONTENTS

TG   Tainter Gate Record
Four Records Required

Record 1

    Col 1+2 TG

    1   Kp +   Use the given pier contraction coefficient.

               0   Use no pier contraction coefficient.

               -   Use the internal tables to generate a pier contraction coefficient.

    2   Ka +   Use the given abutment contraction coefficient.

               0   Use no abutment contraction coefficient.

               -   Use the internal tables to generate an abutment contraction coefficient.

    3   C +   Use the given weir flow coefficient.

               0   Use the internal tables to generate a weir flow coefficient.

    4   Approach width, in feet or metres, of channel leading to spillway.

    5   Approach depth, in feet or metres, of channel leading to spillway.

    6   Height of crest, in feet or metres, above approach apron or approach channel.

    7   Design head, in feet or metres.

    8   Number of piers in the spillway.

    9   Net length, in feet or metres, of the spillway excluding the total width of included piers.

    10   Pier type of the included piers (1-4).

RECORD	FIELD	FIELD CONTENTS

Record 2

Col 1+2   TG

1   Elevation, in feet or metres, of the crest of the spillway.

2   1 The material immediately adjacent to the spillway is concrete.

2   Material immediately adjacent to the spillway is earth.

3   Adjacent section radius, in feet or metres, if the material is concrete.

4   Cs   +   Use the given submergence coefficient.

0   Make no correction for submergence.

-    Use the internal tables to generate a submergence coefficient.

5   Number of slope face correction factor pairs for non-vertical slopes that will appear on the following records (maximum of 99)

6   The width, in feet or metres, of one single gate.

7   Number of different gate openings for which to compute rating curves (maximum of 10).

8   Gate opening to use in routing, if routing is done. It must match one of those given on TG record No. 3.

Record 3

Col 1+2   TG

1-10   Head, in feet or metres, over the spillway corresponding to the following slope face correction factors. Use as many records as required with 10 values per record.

Record 4

Col 1+2   TG

1-10   Slope face correction factors corresponding to the previous heads over the spillway.

RECORD	FIELD	FIELD CONTENTS

Record 5
- Col 1+2   TG

- 1 - 10   Actual gate openings, in feet or metres, for which to compute rating curves (maximum of 10 values).

Record 6
- Col 1+2   TG

- 1 - 10   Discharge coefficients associated with the gate openings given on TG record No. 5 (maximum of 10 values).

RECORD	FIELD	FIELD CONTENTS

VL   Vertical Lift Gate Record
             Four Records Required

Record 1

      Col 1+2 VL

        1   K_p +   Use the given pier contraction coefficient.

                   0   Use no pier contraction coefficient.

                   -     Use the internal tables to generate a pier contraction coefficient.

        2   K_a +   Use the given abutment contraction coefficient.

                   0   Use no abutment contraction coefficient.

                   -     Use the internal tables to generate an abutment contraction coefficient.

        3   C +   Use the given weir flow coefficient.

                   0   Use the internal tables to generate a weir flow coefficient.

        4   Approach width, in feet or metres, of channel leading to spillway.

        5   Approach depth, in feet or metres, of channel leading to spillway.

        6   Height of crest, in feet or metres, above approach apron or approach channel.

        7   Design head, in feet or metres.

        8   Number of piers in the spillway.

        9   Net length, in feet or metres, of the spillway excluding the total width of included piers.

       10   Pier type of the included piers (1-4).

RECORD	FIELD	FIELD CONTENTS

Record 2

Col 1+2   VL

1   Elevation, in feet or metres, of the crest of the spillway.

2

1   Material immediately adjacent to the spillway is concrete.

2   Material immediately adjacent to the spillway is earth.

3   Adjacent section radius, in feet or metres, if the material is concrete.

4   Cs   +   Use the given submergence coefficient.

          0   Make no correction for submergence.

          -     Use the internal tables to generate a submergence coefficient.

5   Number of slope face correction factor pairs for non-vertical slopes that will appear on the following records (maximum of 99).

6   Width, in feet or metres, of one single gate.

7   Number of different gate openings for which to compute rating curves (maximum of 10).

8   Gate opening to use in the routing. It must match one of those given on the VL record No. 3.

9   Gate seat elevation, in feet or metres.

RECORD	FIELD	FIELD CONTENTS

Record 3

Col 1+2 VL

1-10 Head, in feet or metres, over the spillway corresponding to the following slope face correction factors. Use as many records as required with 10 values per record.

Record 4

Col 1+2 VL

1-10 Slope face correction factors corresponding to the previous heads over the spillway.

Record 5

Col 1+2 VL

1 - 10 The actual gate openings, in feet or metres, for which to compute rating curves (maximum of 10 values).

RECORD	FIELD	FIELD CONTENTS

OW   Outlet Works Record

Col 1+2   OW

1   1. Use Manning's equation and the following data for Manning's equation.

        2 Use the Darcy-Weisbach equation and the following data for the Darcy-Weisbach equation.

        2 Diameter, in feet or metres, of the outlet works.

        3 Length, in feet or metres, of the outlet works.

        4 Manning's n if field 1 above is a 1 or the absolute roughness, e, if field 1 above is a 2.

        5 Top of exit portal elevation, in feet or metres.

        6 Entry invert elevation, in feet or metres.

        7 Sum of all other loss coefficients, k, other than the frictional losses in the outlet works.

        8 Blank if field 1 above is a 1 or the kinematic viscosity, v, (entered as X 10^5; i.e., 1.217 X 10^{-5} is entered as 1.217) if field 1 above is a 2. NOTE: is the default if a 0 is entered for kinematic viscosity.

ZZ   If no routing is requested, enter a ZZ card here.

RECORD	FIELD	FIELD CONTENTS

S Records   Reservoir Storage Records

SN   Reservoir Basic Data Record (one required)

         Col 1+2   SN.

           1   Number of input pairs to follow (maximum of 99).

SE   Reservoir Water Surface Elevation (required)

         Col 1+2   SE.

         1 - 10   Reservoir surface elevations, in feet or metres, from the lowest to the highest. Use 10 values per record with as many records as required. If evaporation is to be calculated, this record is required.

SV   Reservoir Storage Volume Record (either SV or SA required)

         Col 1+2   SV.

         1 - 10   Reservoir storage volumes in acre-feet or 1,000 m³ corresponding to the elevations given on the SE record(s).

SA   Reservoir Storage Area Record (either SV or SA required)

         Col 1+2   SA.

         1 - 10   Reservoir surface area in acres or hectares corresponding to the elevations given on the SE record(s).

RECORD	FIELD	FIELD CONTENTS

IC   Initial Conditions Record (one required)

        Col 1+2 IC.

           1   1 The value in field 2 is an elevation.

                  2 The value in field 2 is storage.

           2   Initial storage (acre-feet or 1,000 m^3) or water surface elevation (feet or metres) in the reservoir. NOTE: If the breach routine is being used, the initial elevation must be less than the elevation at which the breach will occur.

           3   Time step for calculation of the outflow hydrograph in hours.

           4   The number of outflow points to generate at each time step in field 3 above (maximum of 99).

H Records   Inflow Hydrograph Records

HN   Inflow Hydrograph Basic Data Record (one required)

        Col 1+2 HN

           1   Time increment for input hydrograph points (hrs).

           2   Number of inflow hydrograph points to follow (maximum of 99).

           3   Starting day of the month for inflow hydrograph points.

           4   Starting month for inflow hydrograph points (numeric field 1-12).

           5   Starting year for the inflow hydrograph points (two or four digits).

           6   Starting time for the inflow hydrograph points (24-hour format).

RECORD	FIELD	FIELD CONTENTS

HI   Inflow Hydrograph Record (required)

          Col 1+2 HI

          1 - 10   Values of inflow hydrograph at the end of each time increment in field 1 of HN record in cfs or m^3/s. Use as many records as required.

Routing Records
NOTE: If no routing is chosen, only the rating curves will be computed and output.

DB   Dam Breach Record

Record 1

          Col 1+2 DB

            1   Elevation, in feet or metres, of the top of the dam.

            2   Elevation, in feet or metres, of the top of the breach.

            3   The initial width, in feet or metres, of the breach.

            4   Elevation, in feet or metres, of the bottom of the breach.

            5   The final width, in feet or metres, of the breach.

            6   The side slope of the breach, in units horizontal to one unit vertical.

            7   The time required to reach maximum breach size, in hours.

            8   Weir flow coefficient for a rectangular weir. If 0 is entered, 3.1 will default.

            9   Weir flow coefficient for a triangular weir. If 0 is entered, 2.45 will default.

           10   Width of the reservoir at the dam, in feet or metres.

RECORD	FIELD	FIELD CONTENTS

Record 2

    Col 1+2 DB

        1   Evaporation rate, in inches or cm, per time increment of the routing.

PL   Modified Puls Record

    Col 1+2 PL

DD   Drawdown Record

Record 1

    Col 1+2 DD

        1   Evaporation rate, in inches or cm, per time increment of the routing.

        2   Number of points in limiting downstream hydrograph (maximum of 99).

        3   Timestep used in the following hydrograph, in hours.

Record 2

    Col 1+2 DD

      1 - 10 Limiting outflow hydrograph points, in cfs or m³/s. Use as many cards as required with 10 values per card.

ZZ   End of Job Card

APPENDIX B: EXAMPLE PROBLEMS

1.   A series of eight example problems are presented here to illustrate
the capabilities of RESOUT. The first six examples consist of computing rat-
ing curves for various types of outlet structures. Example 7 is a drawdown
analysis, which combines rating curve and routing computations. Example 8 is
a breach simulation. The model output, including an input data listing, is
reproduced for each example. The reader should refer to Appendix A for a
description of each of the input data records used in the examples.

Example 1: Rating Curves for an Ogee Spillway, with Tainter Gate, and Outlet Works

2.   The first example involves developing rating curves for alternative
gate openings for a single tainter gate on an ogee spillway. A rating curve
for the outlet works is also computed and combined with the spillway rating
curve for a specified gate opening.

3.   The RESOUT output for this example is presented on the following
pages. As indicated by the input data echo included in the output, header
information is provided by the required three model run identifier (ID)
records and one reservoir identifier (KK) record. The output control (IO)
record specifies that the input data file be echoed to the output file and
that English units be used. Thus, the discharges in the computed outlet
structure rating tables are given in units of cubic feet per second.

4.   A rating table (water surface elevation in feet versus discharge in
cubic feet per second) for the channel downstream of the dam is provided by
the channel geometry (CG), elevation (EL), and discharge (DC) records. This
tailwater rating curve is used by the model to test and correct the spillway
discharge for submergence conditions.

5.   The outflow information (ON) record specifies two outlet structures
(outlet works and gated ogee spillway), with discharges to be computed for
40 evenly spaced reservoir water surface elevations between 465 and 505 feet.

6.   The first tainter gate (TG) record and first five fields of the
second TG record provide the input data used by the model to compute
discharges over the uncontrolled weir for reservoir water surface elevations
below the elevation at which gate control occurs. The first TG record speci-
fies use of the abutment contraction and discharge coefficient data coded into
the model. Since a single gate bay is being modeled, piers are not included

in the computations. The spillway approach width and depth are 440 and
85 feet, respectively. The spillway crest height, crest elevation, and design
head are 25, 465, and 40 feet, respectively. The net width for the single bay
is 40 feet.

7. Fields 6, 7, and 8 of the second TG record and the fifth and sixth
TG records provide the input data used by the model to compute discharges
through gate openings. Rating tables are to be computed for gate openings of
2, 4, 6, 8, 10, and 40 ft, which have corresponding discharge coefficients of
0.68, 0.68, 0.68, 0.68, 0.71, and 0.71. The rating curves for the first gate
opening (2 ft) and the outlet works will be combined to develop a total rating
curve for the reservoir.

8. Since corrections to the weir discharge coefficients for a sloping
upstream face or for other miscellaneous factors are not required, a discharge
coefficient multiplier of 1.0 is specified for the full range of heads by the
third and fourth TG records.

9. The outlet works (OW) record indicates that the 20-ft-diam conduit
has a length of 576 ft, a roughness coefficient (n) of 0.013, a top of exit
portal elevation of 405 ft, and an entrance invert elevation of 400 ft. The
Manning equation is to be used to compute frictional head losses in the con-
duit. The sum of the loss coefficients for all outlet works components other
than the conduit is 1.5.

10. The model prints out warning messages whenever the limits of the
internal tables of empirical data are exceeded. In this example, a warning is
printed in regard to computing the submergence correction factor. The sub-
mergence correction factor is determined by the program as a function of the
ratio of design head (HD) to computed energy head (He). When the HD/He ratio
exceeds 0.9, a value of 0.9 is used and a warning message is printed.

11. The output includes a list of the spillway gate openings and cor-
responding reservoir water surface elevations at which the computations shift
from the weir equation to the orifice equation. Rating tables (water surface
elevation in feet versus discharge in cubic feet per second) are provided for
each of the six gate openings. The last page of the output consists of rating
tables for the spillway with a gate opening of 2 ft (structure 1) and the out-
let works (structure 2). The two rating tables are summed to obtain a total
rating curve for the reservoir.

```
XXXXX  XXXXX  XXXXX  XXXXX  X   X  XXXXX
X   X  X      X      X      X X X X    X
X   X  X      X      X      X X X X    X
XXXXX  XXXX   XXXXX  X   X  X X X X    X
X X    X             X X X X X   X     X
X X    X             X X X X X   X     X
X   X  XXXXX  XXXXX  XXXXX  XXXXX      X
```

Reservoir Outflow Model

Developed

by

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for

Environmental Systems Division
US Army Engineer Waterways Experiment Station

Figure B1.   RESOUT output for sample problem 1
(Sheet 1 of 6)

Example 1
Rating curves for an Ogee Spillway, with Tainter Gate,
and Outlet Works

ID Example 1
ID Rating curves for an Ogee Spillway, with Tainter Gate,
ID and Outlet Works
IO 1 0
KK Test Reservoir
CG 0 0 2 10
EL 370 380 390 400 405 410 415 420 425 430
DC 0 5000 12500 35000 55000 90000 143000 230000 367000 535000
ON 2 465 505 40
TG 0 -1 0 440 85 25 40 0 40 0
TG 465 1 4 -1 2 40 6 2
TG 0 45
TG 1 1
TG 2 4 6 8 10 40
TG .68 .68 .68 .68 .71 .71
OW 1 20 576 .013 405 400 1.5
ZZ
 The Units are English

KK Test Reservoir

Tainter Gates on the Spillway Crest
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 29
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 30
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 31
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 32
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 33
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 34
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 35
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 36
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 37
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 38
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 39
-*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 40
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 41
Outlet Works

Figure B1.   (Sheet 2 of 6)

B4

Gate Opening Number   1 is   2.00 Feet
Flow through this gate became orifice flow at   468.00 Feet elevation
Gate Opening Number   2 is   4.00 Feet
Flow through this gate became orifice flow at   470.00 Feet elevation
Gate Opening Number   3 is   6.00 Feet
Flow through this gate became orifice flow at   472.00 Feet elevation
Gate Opening Number   4 is   8.00 Feet
Flow through this gate became orifice flow at   474.00 Feet elevation
Gate Opening Number   5 is   10.00 Feet
Flow through this gate became orifice flow at   476.00 Feet elevation
Gate Opening Number   6 is   40.00 Feet
Flow through this gate became orifice flow at   0.00 Feet elevation

Figure B1.   (Sheet 3 of 6)

Elevation	1	2	3	4	5
465.00	0.00	0.00	0.00	0.00	0.00
466.00	124.72	124.72	124.72	124.72	124.72
467.00	352.01	352.01	352.01	352.01	352.01
468.00	617.39	645.30	645.30	645.30	645.30
469.00	756.14	991.35	991.35	991.35	991.35
470.00	873.12	1512.28	1382.45	1382.45	1382.45
471.00	976.17	1746.23	1813.34	1813.34	1813.34
472.00	1069.34	1952.35	2619.35	2280.09	2280.09
473.00	1155.02	2138.69	2928.52	2779.67	2779.67
474.00	1234.77	2310.05	3208.03	3904.69	3309.57
475.00	1309.67	2469.54	3465.07	4277.38	3867.73
476.00	1380.52	2619.35	3704.32	4620.09	5582.60
477.00	1447.90	2761.03	3929.02	4939.09	6029.90
478.00	1512.28	2895.80	4141.55	5238.69	6446.24
479.00	1574.03	3024.56	4343.70	5522.07	6837.27
480.00	1633.45	3148.06	4536.84	5791.60	7207.11
481.00	1690.78	3266.90	4722.10	6049.12	7558.88
482.00	1746.23	3381.56	4900.35	6296.13	7895.00
483.00	1799.97	3492.46	5072.34	6533.80	8217.37
484.00	1852.16	3599.95	5238.69	6763.13	8527.57
485.00	1902.91	3704.32	5399.92	6984.93	8826.87
486.00	1952.35	3805.82	5556.47	7199.90	9116.36
487.00	2000.56	3904.69	5708.74	7408.63	9396.92
488.00	2047.64	4001.12	5857.04	7611.65	9669.36
489.00	2093.66	4095.28	6001.68	7809.39	9934.32
490.00	2138.69	4187.32	6142.91	8002.24	10192.40
491.00	2182.79	4277.38	6280.97	8190.55	10444.10
492.00	2226.02	4365.58	6416.06	8374.63	10689.88
493.00	2268.42	4452.03	6548.37	8554.75	10930.13
494.00	2310.05	4536.84	6678.05	8731.16	11165.21
495.00	2350.94	4620.09	6805.26	8904.07	11395.44
496.00	2391.13	4701.87	6930.14	9073.69	11621.12
497.00	2430.65	4782.25	7052.81	9240.19	11842.49
498.00	2469.54	4861.30	7173.38	9403.75	12059.81
499.00	2507.83	4939.09	7291.95	9564.50	12273.27
500.00	2545.55	5015.67	7408.63	9722.61	12483.08
501.00	2582.71	5091.10	7523.50	9878.18	12689.43
502.00	2619.35	5165.42	7636.64	10031.34	12892.47
503.00	2655.48	5238.69	7748.13	10182.19	13092.37
504.00	2691.12	5310.96	7858.04	10330.85	13289.26
505.00	2726.30	5382.25	7966.43	10477.39	13483.27

Figure B1. (Sheet 4 of 6)

Tainter Gate Rating Curves For Gate Number 1

Elevation	6	7	8	9	10
465.00	0.00				
466.00	124.72				
467.00	352.01				
468.00	645.30				
469.00	991.35				
470.00	1382.45				
471.00	1813.34				
472.00	2280.09				
473.00	2779.67				
474.00	3309.57				
475.00	3867.73				
476.00	4452.37				
477.00	5061.96				
478.00	5695.13				
479.00	6350.69				
480.00	7027.55				
481.00	7724.72				
482.00	8441.32				
483.00	9176.50				
484.00	9929.52				
485.00	10699.67				
486.00	11486.28				
487.00	12288.75				
488.00	13106.48				
489.00	13938.94				
490.00	14785.61				
491.00	15646.00				
492.00	16519.65				
493.00	17406.12				
494.00	18304.98				
495.00	19215.83				
496.00	20138.29				
497.00	21071.98				
498.00	22016.55				
499.00	22971.67				
500.00	23937.00				
501.00	24912.21				
502.00	25897.02				
503.00	26891.12				
504.00	27894.22				
505.00	28906.04				

Figure B1. (Sheet 5 of 6)

Outflow Rating Curves

Outflow Structure Number 1 is a Tainter Gate on Spillway Crest at an opening of 2.00 Feet
Outflow Structure Number 2 is an Outlet Works

| | | Outflow Structure | | | | |
Elevation	1	2	3	4	5	Total
465.00	0.00	15414.19	0.00	0.00	0.00	15414.19
466.00	124.72	15528.95	0.00	0.00	0.00	15653.67
467.00	352.01	15643.71	0.00	0.00	0.00	15995.72
468.00	617.39	15758.47	0.00	0.00	0.00	16375.86
469.00	756.14	15871.53	0.00	0.00	0.00	16627.67
470.00	873.12	15983.28	0.00	0.00	0.00	16856.40
471.00	976.17	16093.67	0.00	0.00	0.00	17069.84
472.00	1069.34	16203.06	0.00	0.00	0.00	17272.40
473.00	1155.02	16311.87	0.00	0.00	0.00	17466.89
474.00	1234.77	16420.03	0.00	0.00	0.00	17654.80
475.00	1309.67	16527.21	0.00	0.00	0.00	17836.88
476.00	1380.52	16633.88	0.00	0.00	0.00	18014.39
477.00	1447.90	16739.87	0.00	0.00	0.00	18187.77
478.00	1512.28	16845.00	0.00	0.00	0.00	18357.28
479.00	1574.03	16949.70	0.00	0.00	0.00	18523.73
480.00	1633.45	17053.56	0.00	0.00	0.00	18687.01
481.00	1690.78	17156.82	0.00	0.00	0.00	18847.61
482.00	1746.23	17259.64	0.00	0.00	0.00	19005.88
483.00	1799.97	17361.51	0.00	0.00	0.00	19161.49
484.00	1852.16	17463.07	0.00	0.00	0.00	19315.22
485.00	1902.91	17563.82	0.00	0.00	0.00	19466.74
486.00	1952.35	17664.08	0.00	0.00	0.00	19616.43
487.00	2000.56	17763.83	0.00	0.00	0.00	19764.39
488.00	2047.64	17862.84	0.00	0.00	0.00	19910.48
489.00	2093.66	17961.58	0.00	0.00	0.00	20055.24
490.00	2138.69	18059.40	0.00	0.00	0.00	20198.09
491.00	2182.79	18157.06	0.00	0.00	0.00	20339.85
492.00	2226.02	18253.82	0.00	0.00	0.00	20479.84
493.00	2268.42	18350.38	0.00	0.00	0.00	20618.80
494.00	2310.05	18446.16	0.00	0.00	0.00	20756.21
495.00	2350.94	18541.66	0.00	0.00	0.00	20892.60
496.00	2391.13	18636.48	0.00	0.00	0.00	21027.61
497.00	2430.65	18730.98	0.00	0.00	0.00	21161.63
498.00	2469.54	18824.85	0.00	0.00	0.00	21294.39
499.00	2507.83	18918.38	0.00	0.00	0.00	21426.21
500.00	2545.55	19011.30	0.00	0.00	0.00	21556.85
501.00	2582.71	19103.93	0.00	0.00	0.00	21686.64
502.00	2619.35	19195.91	0.00	0.00	0.00	21815.26
503.00	2655.48	19287.68	0.00	0.00	0.00	21943.15
504.00	2691.12	19378.74	0.00	0.00	0.00	22069.86
505.00	2726.30	19469.68	0.00	0.00	0.00	22195.99

Figure B1. (Sheet 6 of 6)

12. The second example uses the same reservoir as the first example. the only difference is that the spillway rating curve includes flow through 14 tainter gates. All gates have the same opening. Rating curves are developed for six alternative gate openings. Thirteen type 2 piers are added to the input data.

Example 2
Rating Curves for an Ogee Spillway with Multiple Tainter Gates
and Outlet Works


```
ID Example 2
ID Rating Curves for an Ogee Spillway with Multiple Tainter Gates
ID
IO 1 0
KK Test Reservoir
CG 0 0 2 10
EL 370 380 390 400 405 410 415 420 425 430
DC 0 5000 12500 35000 55000 90000 143000 230000 367000 535000
ON 2 465 505 40
TG 0 -1 0 664 85 25 40 13 560 2
TG 465 1 4 -1 2 40 6 2
TG 0 45
TG 1 1
TG 2 4 6 8 10 40
TG .68 .68 .68 .68 .71 .71
OW 1 20 576 .013 405 400 1.5
ZZ
```

Figure B2.   RESOUT output for example problem 2 (Sheet 1 of 5)

The Units are English

KK Test Reservoir

Tainter Gates on the Spillway Crest

*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 29
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 30
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 31
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 32
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 33
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 34
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 35
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 36
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 37
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 38
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 39
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 40
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 41
Outlet Works

Tainter Gate Rating Curves For Gate Number 1

Gate Opening Number   1 is   2.00 Feet
Flow through this gate became orifice flow at   468.00 Feet   elevation
Gate Opening Number   2 is   4.00 Feet
Flow through this gate became orifice flow at   470.00 Feet   elevation
Gate Opening Number   3 is   6.00 Feet
Flow through this gate became orifice flow at   472.00 Feet   elevation
Gate Opening Number   4 is   8.00 Feet
Flow through this gate became orifice flow at   474.00 Feet   elevation
Gate Opening Number   5 is   10.00 Feet
Flow through this gate became orifice flow at   476.00 Feet   elevation
Gate Opening Number   6 is   40.00 Feet
Flow through this gate became orifice flow at   0.00 Feet   elevation

Figure B2. (Sheet 2 of 5)

Elevation	1	2	3	4	5
465.00	0.00	0.00	0.00	0.00	0.00
466.00	1741.96	1741.96	1741.96	1741.96	1741.96
467.00	4904.71	4904.71	4904.71	4904.71	4904.71
468.00	8643.41	8969.91	8969.91	8969.91	8969.91
469.00	10585.97	13747.95	13747.95	13747.95	13747.95
470.00	12223.62	21171.93	19127.05	19127.05	19127.05
471.00	13666.42	24447.24	25030.32	25030.32	25030.32
472.00	14970.82	27332.85	36670.86	31400.26	31400.26
473.00	16170.33	29941.63	40999.27	38191.49	38191.49
474.00	17286.81	32340.66	44912.45	54665.70	45366.83
475.00	18335.43	34573.62	48510.99	59883.27	52894.95
476.00	19327.24	36670.86	51860.43	64681.33	78156.47
477.00	20270.58	38654.48	55006.29	69147.24	84418.64
478.00	21171.93	40541.17	57981.73	73341.73	90247.31
479.00	22036.45	42343.87	60811.75	77308.97	95721.74
480.00	22868.30	44072.89	63515.80	81082.34	100899.60
481.00	23670.94	45736.60	66109.34	84687.73	105824.40
482.00	24447.24	47341.88	68604.90	88145.78	110529.90
483.00	25199.64	48894.49	71012.81	91473.20	115043.20
484.00	25930.22	50399.28	73341.73	94683.76	119386.00
485.00	26640.77	51860.43	75598.91	97788.98	123576.20
486.00	27332.85	53281.53	77790.65	100798.60	127629.00
487.00	28007.83	54665.70	79922.30	103720.90	131556.90
488.00	28666.93	56015.67	81998.54	106563.10	135371.00
489.00	29311.21	57333.87	84023.49	109331.40	139080.50
490.00	29941.63	58622.43	86000.79	112031.30	142693.50
491.00	30559.05	59883.27	87933.64	114667.70	146217.40
492.00	31164.24	61118.11	89824.91	117244.90	149658.30
493.00	31757.90	62328.48	91677.16	119766.50	153021.80
494.00	32340.66	63515.80	93492.72	122236.20	156312.90
495.00	32913.11	64681.33	95273.70	124657.00	159536.20
496.00	33475.77	65826.22	97021.98	127031.60	162695.70
497.00	34029.12	66951.53	98739.32	129362.70	165794.90
498.00	34573.62	68058.24	100427.30	131652.40	168837.30
499.00	35109.68	69147.24	102087.40	133903.10	171825.80
500.00	35637.67	70219.36	103720.90	136116.50	174763.20
501.00	36157.96	71275.34	105329.00	138294.50	177652.00
502.00	36670.86	72315.92	106913.00	140438.70	180494.60
503.00	37176.69	73341.73	108473.90	142550.70	183293.20
504.00	37675.73	74353.38	110012.60	144631.80	186049.60
505.00	38168.25	75351.46	111530.10	146683.50	188765.80

Figure B2. (Sheet 3 of 5)

Tainter Gate Rating Curves For Gate Number 1

Elevation	6	7	8	9	10
465.00	0.00				
466.00	1741.96				
467.00	4904.71				
468.00	8969.91				
469.00	13747.95				
470.00	19127.05				
471.00	25030.32				
472.00	31400.26				
473.00	38191.49				
474.00	45366.83				
475.00	52894.95				
476.00	60748.87				
477.00	68904.98				
478.00	77342.26				
479.00	86041.84				
480.00	94986.62				
481.00	104160.90				
482.00	113550.20				
483.00	123141.00				
484.00	132921.00				
485.00	142878.10				
486.00	153001.60				
487.00	163280.70				
488.00	173705.60				
489.00	184266.80				
490.00	194955.30				
491.00	205762.30				
492.00	216679.70				
493.00	227699.30				
494.00	238813.50				
495.00	250014.90				
496.00	261296.30				
497.00	272650.70				
498.00	284071.40				
499.00	295552.00				
500.00	307085.90				
501.00	318667.30				
502.00	330289.80				
503.00	341947.80				
504.00	353635.60				
505.00	365347.60				

Figure B2. (Sheet 4 of 5)

Outflow Rating Curves

Outflow Structure Number 1 is a Tainter Gate on Spillway Crest   at an
opening of   2.00 Feet
Outflow Structure Number 2 is an Outlet Works

Elevation	1	2	Outflow Structure 3	4	5	Total
465.00	0.00	15414.19	0.00	0.00	0.00	15414.19
466.00	1741.96	15528.95	0.00	0.00	0.00	17270.91
467.00	4904.71	15643.71	0.00	0.00	0.00	20548.43
468.00	8643.41	15758.47	0.00	0.00	0.00	24401.88
469.00	10585.97	15871.53	0.00	0.00	0.00	26457.50
470.00	12223.62	15983.29	0.00	0.00	0.00	28206.91
471.00	13666.42	16093.67	0.00	0.00	0.00	29760.09
472.00	14970.82	16203.06	0.00	0.00	0.00	31173.88
473.00	16170.33	16311.88	0.00	0.00	0.00	32482.21
474.00	17286.81	16420.04	0.00	0.00	0.00	33706.85
475.00	18335.43	16527.21	0.00	0.00	0.00	34862.64
476.00	19327.24	16633.88	0.00	0.00	0.00	35961.13
477.00	20270.58	16739.88	0.00	0.00	0.00	37010.46
478.00	21171.93	16845.01	0.00	0.00	0.00	38016.94
479.00	22036.45	16949.71	0.00	0.00	0.00	38986.16
480.00	22868.30	17053.57	0.00	0.00	0.00	39921.88
481.00	23670.94	17156.83	0.00	0.00	0.00	40827.77
482.00	24447.24	17259.65	0.00	0.00	0.00	41706.89
483.00	25199.64	17361.52	0.00	0.00	0.00	42561.16
484.00	25930.22	17463.07	0.00	0.00	0.00	43393.29
485.00	26640.77	17563.83	0.00	0.00	0.00	44204.60
486.00	27332.85	17664.09	0.00	0.00	0.00	44996.94
487.00	28007.83	17763.83	0.00	0.00	0.00	45771.67
488.00	28666.93	17862.85	0.00	0.00	0.00	46529.79
489.00	29311.21	17961.59	0.00	0.00	0.00	47272.80
490.00	29941.63	18059.41	0.00	0.00	0.00	48001.04
491.00	30559.05	18157.07	0.00	0.00	0.00	48716.13
492.00	31164.24	18253.83	0.00	0.00	0.00	49418.07
493.00	31757.90	18350.38	0.00	0.00	0.00	50108.29
494.00	32340.66	18446.17	0.00	0.00	0.00	50786.83
495.00	32913.11	18541.67	0.00	0.00	0.00	51454.78
496.00	33475.77	18636.49	0.00	0.00	0.00	52112.25
497.00	34029.12	18730.98	0.00	0.00	0.00	52760.11
498.00	34573.62	18824.85	0.00	0.00	0.00	53398.47
499.00	35109.68	18918.39	0.00	0.00	0.00	54028.07
500.00	35637.67	19011.31	0.00	0.00	0.00	54648.98
501.00	36157.96	19103.93	0.00	0.00	0.00	55261.89
502.00	36670.86	19195.92	0.00	0.00	0.00	55866.79
503.00	37176.69	19287.68	0.00	0.00	0.00	56464.38
504.00	37675.73	19378.74	0.00	0.00	0.00	57054.48
505.00	38168.25	19469.69	0.00	0.00	0.00	57637.94

(Figure B2.   (Sheet 5 of 5)

Example 3: Rating Curves for an Ogee Spillway
with a Vertical Lift Gate

13. The third example consists of computing rating tables for four alternative gate openings for a single vertical lift gate on an ogee spillway.

```
Example 3
Rating Curves for an Ogee Spillway with a Vertical
Lift Gate

ID Example 3
ID Rating Curves for an Ogee Spillway with a Vertical
ID Lift Gate
IO 1 0
KK Test Reservoir
CG 0 0 2 10
EL 390 400 410 420 425 430 435 440 445 450
DC 0 500 1250 3500 4500 4800 6000 8000 10000 100000
ON 1 465 505 40
VL 0 -1 0 440 85 25 40 0 40 0
VL 465 1 4 -1 2 40 4 2 463
VL 0 45
VL 1 1
VL 1 2 3 5
ZZ
```

Figure B3. RESOUT output for example problem 3 (Sheet 1 of 4)

The Units are English

KK Test Reservoir

Vertical Lift Gates

*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 23
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 24
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 25
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 26
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 27
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 28
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 29
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 30
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 31
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 32
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 33
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 34
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 35
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 36
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 37
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 38
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 39
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 40
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 41

Vertical Lift Gate Rating Curves For Gate Number 1

Gate Opening Number   1 is   1.00 Feet
Flow through this gate became orifice flow at   465.00 Feet   elevation
Gate Opening Number   2 is   2.00 Feet
Flow through this gate became orifice flow at   466.00 Feet   elevation
Gate Opening Number   3 is   3.00 Feet
Flow through this gate became orifice flow at   467.00 Feet   elevation
Gate Opening Number   4 is   5.00 Feet
Flow through this gate became orifice flow at   469.00 Feet   elevation

Figure B3. (Sheet 2 of 4)

B15

Elevation	1	2	3	4	5
465.00	0.00	0.00	0.00	0.00	
466.00	124.72	124.72	124.72	124.72	
467.00	348.96	352.01	352.01	352.01	
468.00	394.96	645.30	645.30	645.30	
469.00	435.77	829.88	991.35	991.35	
470.00	472.76	907.58	1300.83	1382.45	
471.00	506.75	978.48	1412.36	1813.34	
472.00	538.32	1043.97	1514.67	2280.09	
473.00	567.89	1105.04	1609.58	2511.25	
474.00	595.73	1162.38	1698.36	2670.45	
475.00	622.10	1216.53	1781.94	2819.08	
476.00	647.17	1267.91	1861.04	2958.83	
477.00	671.09	1316.84	1936.21	3090.96	
478.00	693.97	1363.58	2007.91	3216.44	
479.00	715.92	1408.37	2076.50	3336.05	
480.00	737.03	1451.37	2142.28	3450.41	
481.00	757.35	1492.75	2205.50	3560.06	
482.00	776.96	1532.63	2266.39	3665.41	
483.00	795.91	1571.15	2325.13	3766.85	
484.00	814.25	1608.38	2381.88	3864.68	
485.00	832.00	1644.43	2436.79	3959.18	
486.00	849.23	1679.37	2489.97	4050.59	
487.00	865.95	1713.26	2541.54	4139.13	
488.00	882.19	1746.18	2591.59	4224.96	
489.00	897.98	1778.18	2640.22	4308.27	
490.00	913.35	1809.30	2687.50	4389.19	
491.00	928.32	1839.59	2733.51	4467.87	
492.00	942.90	1869.10	2778.31	4544.42	
493.00	957.11	1897.86	2821.95	4618.94	
494.00	970.98	1925.90	2864.50	4691.55	
495.00	984.51	1953.26	2906.00	4762.33	
496.00	997.72	1979.97	2946.50	4831.36	
497.00	1010.62	2006.05	2986.04	4898.72	
498.00	1023.23	2031.53	3024.66	4964.48	
499.00	1035.56	2056.43	3062.40	5028.71	
500.00	1047.62	2080.78	3099.29	5091.47	
501.00	1059.41	2104.59	3135.36	5152.81	
502.00	1070.94	2127.88	3170.64	5212.79	
503.00	1082.12	2150.45	3204.81	5270.89	
504.00	1092.95	2172.32	3237.94	5327.20	
505.00	103.55	2193.73	3270.37	5382.31	

Figure B3.   (Sheet 3 of 4)

Outflow Rating Curves

Outflow Structure Number 1 is a Vertical Lift Gate   at an
opening of   2.00 Feet

Elevation			Outflow Structure			
	1	2	3	4	5	Total
465.00	0.00	0.00	0.00	0.00	0.00	0.00
466.00	124.72	0.00	0.00	0.00	0.00	124.72
467.00	352.01	0.00	0.00	0.00	0.00	352.01
468.00	645.30	0.00	0.00	0.00	0.00	645.30
469.00	829.88	0.00	0.00	0.00	0.00	829.88
470.00	907.58	0.00	0.00	0.00	0.00	907.58
471.00	978.48	0.00	0.00	0.00	0.00	978.48
472.00	1043.97	0.00	0.00	0.00	0.00	1043.97
473.00	1105.04	0.00	0.00	0.00	0.00	1105.04
474.00	1162.38	0.00	0.00	0.00	0.00	1162.38
475.00	1216.53	0.00	0.00	0.00	0.00	1216.53
476.00	1267.91	0.00	0.00	0.00	0.00	1267.91
477.00	1316.84	0.00	0.00	0.00	0.00	1316.84
478.00	1363.58	0.00	0.00	0.00	0.00	1363.58
479.00	1408.37	0.00	0.00	0.00	0.00	1408.37
480.00	1451.37	0.00	0.00	0.00	0.00	1451.37
481.00	1492.75	0.00	0.00	0.00	0.00	1492.75
482.00	1532.63	0.00	0.00	0.00	0.00	1532.63
483.00	1571.15	0.00	0.00	0.00	0.00	1571.15
484.00	1608.38	0.00	0.00	0.00	0.00	1608.38
485.00	1644.43	0.00	0.00	0.00	0.00	1644.43
486.00	1679.37	0.00	0.00	0.00	0.00	1679.37
487.00	1713.26	0.00	0.00	0.00	0.00	1713.26
488.00	1746.18	0.00	0.00	0.00	0.00	1746.18
489.00	1778.18	0.00	0.00	0.00	0.00	1778.18
490.00	1809.30	0.00	0.00	0.00	0.00	1809.30
491.00	1839.59	0.00	0.00	0.00	0.00	1839.59
492.00	1869.10	0.00	0.00	0.00	0.00	1869.10
493.00	1897.86	0.00	0.00	0.00	0.00	1897.86
494.00	1925.90	0.00	0.00	0.00	0.00	1925.90
495.00	1953.26	0.00	0.00	0.00	0.00	1953.26
496.00	1979.97	0.00	0.00	0.00	0.00	1979.97
497.00	2006.05	0.00	0.00	0.00	0.00	2006.05
498.00	2031.53	0.00	0.00	0.00	0.00	2031.53
499.00	2056.43	0.00	0.00	0.00	0.00	2056.43
500.00	2080.78	0.00	0.00	0.00	0.00	2080.78
501.00	2104.59	0.00	0.00	0.00	0.00	2104.59
502.00	2127.88	0.00	0.00	0.00	0.00	2127.88
503.00	2150.45	0.00	0.00	0.00	0.00	2150.45
504.00	2172.32	0.00	0.00	0.00	0.00	2172.32
505.00	2193.73	0.00	0.00	0.00	0.00	2193.73

Figure B3.   (Sheet 4 of 4)

Example 4: Rating Curve for an Uncontrolled
Broad-crested Weir

14.   Example 4 consists of computing a spillway rating curve for an uncontrolled broad-crested weir. A representative downstream channel cross section is described on the CG, CE, and CT records for use by the model in developing a tailwater rating curve for the submergence computations.

```
 Example 4
 Rating Curve for an an uncontrolled broadcrested weir spillway

ID Example 4
ID Rating Curve for an an uncontrolled broadcrested weir spillway
ID
IO 1 0
KK Test Reservoir
CG .0004 .03 1 10
CE 480 490 500 510 520 530 540 550 560 570
CT 1000 1300 1500 1600 1700 1800 1900 2000 2100 2500
ON 1 630 660 20
UB 0 0 631 1300 2 3300 60 1
ZZ
```

Figure B4.   RESOUT output for example problem 4 (Continued)

The Units are English

KK Test Reservoir

Uncontrolled Broad-crested Weir

Outflow Rating Curves

Outflow Structure Number 1 is an Uncontrolled Broad-crested Weir

Elevation	1	2	Outflow Structure 3	4	5	Total
630.00	0.00	0.00	0.00	0.00	0.00	0.00
631.50	1419.71	0.00	0.00	0.00	0.00	1419.71
633.00	11378.91	0.00	0.00	0.00	0.00	11378.91
634.50	26392.75	0.00	0.00	0.00	0.00	26392.75
636.00	45152.54	0.00	0.00	0.00	0.00	45152.54
637.50	67059.36	0.00	0.00	0.00	0.00	67059.36
639.00	91749.68	0.00	0.00	0.00	0.00	91749.68
640.50	118974.40	0.00	0.00	0.00	0.00	118974.40
642.00	148550.50	0.00	0.00	0.00	0.00	148550.50
643.50	180337.40	0.00	0.00	0.00	0.00	180337.40
645.00	214223.70	0.00	0.00	0.00	0.00	214223.70
646.50	250119.20	0.00	0.00	0.00	0.00	250119.20
648.00	287949.70	0.00	0.00	0.00	0.00	287949.70
649.50	327653.30	0.00	0.00	0.00	0.00	327653.30
651.00	369178.00	0.00	0.00	0.00	0.00	369178.00
652.50	412480.20	0.00	0.00	0.00	0.00	412480.20
654.00	457522.70	0.00	0.00	0.00	0.00	457522.70
655.50	504274.20	0.00	0.00	0.00	0.00	504274.20
657.00	552708.60	0.00	0.00	0.00	0.00	552708.60
658.50	602803.50	0.00	0.00	0.00	0.00	602803.50
660.00	654540.90	0.00	0.00	0.00	0.00	654540.90

Figure B4. (Concluded)

15. Example 5 consists of computing a rating curve for a drop inlet spillway.

```
Example 5
Rating Curve for a Drop Inlet Spillway


ID Example 5
ID Rating Curve for a Drop Inlet Spillway
ID
IO 1 0
KK Test Reservoir
CG 0 0 2 1
EL 1
DC 0
ON 1 920 935 15
DI 1 47.75 0 920
ZZ


   The Units are English

KK Test Reservoir

Drop Inlet Spillway

*WARNING H/Rs < .18 - .18 USED FOR COMPUTATION OF Cs#  2
*WARNING P/Rs < .15 - .15 USED FOR COMPUTATION OF Cs#  2
```

Figure B5. RESOUT output for example problem 5 (Continued)

Outflow Rating Curves

Outflow Structure Number 1 is a Drop Inlet Spillway

		Outflow	Structure			
Elevation	1	2	3	4	5	Total
920.00	0.00	0.00	0.00	0.00	0.00	0.00
921.00	1206.09	0.00	0.00	0.00	0.00	1206.09
922.00	3411.33	0.00	0.00	0.00	0.00	3411.33
923.00	6267.02	0.00	0.00	0.00	0.00	6267.02
924.00	9648.70	0.00	0.00	0.00	0.00	9648.70
925.00	13484.47	0.00	0.00	0.00	0.00	13484.47
926.00	17725.80	0.00	0.00	0.00	0.00	17725.80
927.00	22337.06	0.00	0.00	0.00	0.00	22337.06
928.00	27290.65	0.00	0.00	0.00	0.00	27290.65
929.00	32564.37	0.00	0.00	0.00	0.00	32564.37
930.00	38139.85	0.00	0.00	0.00	0.00	38139.85
931.00	44001.55	0.00	0.00	0.00	0.00	44001.55
932.00	50136.13	0.00	0.00	0.00	0.00	50136.13
933.00	56531.95	0.00	0.00	0.00	0.00	56531.95
934.00	63178.75	0.00	0.00	0.00	0.00	63178.75
935.00	70067.38	0.00	0.00	0.00	0.00	70067.38

Figure B5. (Concluded)

Example 6: Rating Curve for an Outlet Works

16. Example 6 consists of computing the rating curve for an outlet works. The Darcy-Weisbach equation is used to compute conduit head losses. In the output rating table, open channel flow is indicated by a series of asterisks (*). Discharges are computed only for pressure conduit flow.

```
 Example 6
 Rating Curve for an Outlet Works


ID Example 6
ID Rating Curve for an Outlet Works
ID
IO 1 0
KK Test Reservoir
CG 0 0 2 1
EL 1
DC 0
ON 1 1250 1380 20
OW 2 22 870 .001 1241 1251 1.25 1.22
ZZ


 The Units are English

KK Test Reservoir

Outlet Works
```

Figure B6. RESOUT output for example problem 6 (Continued)

Outflow Rating Curves

Outflow Structure Number .1 is an Outlet Works

		Outflow	Structure			
Elevation	1	2	3	4	5	Total
1250.00	0.00	0.00	0.00	0.00	0.00	0.00
1256.50	**********	0.00	0.00	0.00	0.00	**********
1263.00	**********	0.00	0.00	0.00	0.00	**********
1269.50	**********	0.00	0.00	0.00	0.00	**********
1276.00	15547.86	0.00	0.00	0.00	0.00	15547.86
1282.50	16702.04	0.00	0.00	0.00	0.00	16702.04
1289.00	17856.21	0.00	0.00	0.00	0.00	17856.21
1295.50	18889.37	0.00	0.00	0.00	0.00	18889.37
1302.00	19861.64	0.00	0.00	0.00	0.00	19861.64
1308.50	20783.14	0.00	0.00	0.00	0.00	20783.14
1315.00	21660.10	0.00	0.00	0.00	0.00	21660.10
1321.50	22500.90	0.00	0.00	0.00	0.00	22500.90
1328.00	23309.89	0.00	0.00	0.00	0.00	23309.89
1334.50	24094.26	0.00	0.00	0.00	0.00	24094.26
1341.00	24852.32	0.00	0.00	0.00	0.00	24852.32
1347.50	25586.22	0.00	0.00	0.00	0.00	25586.22
1354.00	26298.10	0.00	0.00	0.00	0.00	26298.10
1360.50	26990.69	0.00	0.00	0.00	0.00	26990.69
1367.00	27668.11	0.00	0.00	0.00	0.00	27668.11
1373.50	28328.26	0.00	0.00	0.00	0.00	28328.26
1380.00	28970.18	0.00	0.00	0.00	0.00	28970.18

Figure B6. (Concluded)

17. This example illustrates the drawdown analysis capabilities of RESOUT. An inflow hydrograph is routed through the reservoir of example 1. The target release hydrograph is a constant discharge of 60,000 cfs. The reservoir evaporation rate is 0.14 in. per day. The outlet capacity is represented by 14 tainter gates with an opening of 35 ft.

```
 Example 7
 Drawdown Analysis

ID Example 7
ID Drawdown Analysis
ID
IO 1 0
KK Test Reservoir
CG 0 0 2 10
EL 370 380 390 400 405 410 415 420 425 430
DC 0 5000 12500 35000 55000 90000 143000 230000 367000 535000
ON 1 425 505 40
TG -1 -1 0 440 85 25 40 13 560 3
TG 465 1 4 -1 2 40 1 35
TG 0 45
TG 1 1
TG 35
TG .71
SN 14
SE 370 380 390 400 410 420 430 440 450 460
SE 470 480 490 500
SA 0 6 26 52 173 455 3143 4762 6378 8076
SA 10510 13357 16144 19438
SV 0 27 192 579 1604 4296 23000 62548 118047 190568
SV 282962 401742 549044 726360
IC 1 428 24 65
HN 24 65 19 4 1957 1200
HI 5000 20000 35000 10000 10000 80000 90000 15000 65000 50000
HI 80000 62000 66000 82000 10000 10000 9500 12000 50000 32000
HI 21000 11000 12000 100000 32000 40000 65000 44000 38000 41000
HI 42000 35000 37000 40000 40000 45000 48000 50000 75000 54000
HI 65000 47000 41000 35000 34000 35000 30000 30000 30000 28000
HI 25000 18000 16000 16000 15000 9000 7000 8000 5000 4000
HI 5000 7000 5000 5000 5000
DD .14 2 2000
DD 60000 60000
ZZ
```

Figure B7. RESOUT output for example problem 7 (Sheet 1 of 6)

The Units are English

KK Test Reservoir

Tainter Gates on the Spillway Crest

*WARNING H/Hd < .2 - .2 USED FOR COMPUTATION OF Kp# 22
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 35
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 36
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 37
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 38
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 39
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 40
*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs# 41

Figure B7. (Sheet 2 of 6)

Tainter Gate Rating Curves For Gate Number 1

Gate Opening Number   1 is   35.00 Feet
Flow through this gate became orifice flow at   501.00 Feet   elevation

		Gate Opening Number			
Elevation	1	2	3	4	5
425.00	0.00				
427.00	0.00				
429.00	0.00				
431.00	0.00				
433.00	0.00				
435.00	0.00				
437.00	0.00				
439.00	0.00				
441.00	0.00				
443.00	0.00				
445.00	0.00				
447.00	0.00				
449.00	0.00				
451.00	0.00				
453.00	0.00				
455.00	0.00				
457.00	0.00				
459.00	0.00				
461.00	0.00				
463.00	0.00				
465.00	0.00				
467.00	4950.73				
469.00	13899.67				
471.00	25352.64				
473.00	38759.65				
475.00	53794.70				
477.00	70231.89				
479.00	87900.35				
481.00	106663.10				
483.00	126405.90				
485.00	147030.30				
487.00	168449.10				
489.00	190584.30				
491.00	213364.40				
493.00	236723.30				
495.00	260599.40				
497.00	284934.90				
499.00	309674.80				
501.00	480333.80				
503.00	505631.70				
505.00	529722.70				

Figure B7. (Sheet 3 of 6)

Outflow Rating Curves

Outflow Structure Number 1 is a Tainter Gate on Spillway Crest
at an opening of   35.00 Feet

			Outflow Structure			
Elevation	1	2	3	4	5	Total
425.00	0.00	0.00	0.00	0.00	0.00	0.00
427.00	0.00	0.00	0.00	0.00	0.00	0.00
429.00	0.00	0.00	0.00	0.00	0.00	0.00
431.00	0.00	0.00	0.00	0.00	0.00	0.00
433.00	0.00	0.00	0.00	0.00	0.00	0.00
435.00	0.00	0.00	0.00	0.00	0.00	0.00
437.00	0.00	0.00	0.00	0.00	0.00	0.00
439.00	0.00	0.00	0.00	0.00	0.00	0.00
441.00	0.00	0.00	0.00	0.00	0.00	0.00
443.00	0.00	0.00	0.00	0.00	0.00	0.00
445.00	0.00	0.00	0.00	0.00	0.00	0.00
447.00	0.00	0.00	0.00	0.00	0.00	0.00
449.00	0.00	0.00	0.00	0.00	0.00	0.00
451.00	0.00	0.00	0.00	0.00	0.00	0.00
453.00	0.00	0.00	0.00	0.00	0.00	0.00
455.00	0.00	0.00	0.00	0.00	0.00	0.00
457.00	0.00	0.00	0.00	0.00	0.00	0.00
459.00	0.00	0.00	0.00	0.00	0.00	0.00
461.00	0.00	0.00	0.00	0.00	0.00	0.00
463.00	0.00	0.00	0.00	0.00	0.00	0.00
465.00	0.00	0.00	0.00	0.00	0.00	0.00
467.00	4950.73	0.00	0.00	0.00	0.00	4950.73
469.00	13899.67	0.00	0.00	0.00	0.00	13899.67
471.00	25352.64	0.00	0.00	0.00	0.00	25352.64
473.00	38759.65	0.00	0.00	0.00	0.00	38759.65
475.00	53794.70	0.00	0.00	0.00	0.00	53794.70
477.00	70231.89	0.00	0.00	0.00	0.00	70231.89
479.00	87900.35	0.00	0.00	0.00	0.00	87900.35
481.00	106663.10	0.00	0.00	0.00	0.00	106663.10
483.00	126405.90	0.00	0.00	0.00	0.00	126405.90
485.00	147030.30	0.00	0.00	0.00	0.00	147030.30
487.00	168449.10	0.00	0.00	0.00	0.00	168449.10
489.00	190584.30	0.00	0.00	0.00	0.00	190584.30
491.00	213364.40	0.00	0.00	0.00	0.00	213364.40
493.00	236723.30	0.00	0.00	0.00	0.00	236723.30
495.00	260599.40	0.00	0.00	0.00	0.00	260599.40
497.00	284934.90	0.00	0.00	0.00	0.00	284934.90
499.00	309674.80	0.00	0.00	0.00	0.00	309674.80
501.00	480333.80	0.00	0.00	0.00	0.00	480333.80
503.00	505631.70	0.00	0.00	0.00	0.00	505631.70
505.00	529722.70	0.00	0.00	0.00	0.00	529722.70

Figure B7.   (Sheet 4 of 6)

Output Hydrograph for Reservoir: Test Reservoir

Year	Mo	Dy	Hour		Inflow	Outflow	Elevation	Storage
1957	4	19	12	0	5000.0	0.0	428.0	19259.2
1957	4	20	12	0	20000.0	0.0	435.3	44049.3
1957	4	21	12	0	35000.0	0.0	446.5	98544.8
1957	4	22	12	0	10000.0	0.0	453.5	143096.0
1957	4	23	12	0	10000.0	0.0	456.2	162775.1
1957	4	24	12	0	80000.0	3211.7	466.3	248752.7
1957	4	25	12	0	90000.0	60000.0	476.0	354658.5
1957	4	26	12	0	15000.0	55163.4	475.2	344330.1
1957	4	27	12	0	65000.0	43254.2	473.6	325697.5
1957	4	28	12	0	50000.0	54106.2	475.0	342802.2
1957	4	29	12	0	80000.0	60000.0	476.4	358564.6
1957	4	30	12	0	62000.0	60000.0	478.2	380382.8
1957	5	1	12	0	66000.0	60000.0	478.9	388316.5
1957	5	2	12	0	82000.0	60000.0	481.0	416085.2
1957	5	3	12	0	10000.0	60000.0	478.9	388316.5
1957	5	4	12	0	10000.0	35644.0	472.5	313075.3
1957	5	5	12	0	9500.0	17543.4	469.6	279601.6
1957	5	6	12	0	12000.0	12502.2	468.7	270837.0
1957	5	7	12	0	50000.0	25231.2	471.0	294588.1
1957	5	8	12	0	32000.0	36514.6	472.7	314618.1
1957	5	9	12	0	21000.0	29197.6	471.6	301653.0
1957	5	10	12	0	11000.0	20171.4	470.1	284093.0
1957	5	11	12	0	12000.0	13623.2	468.9	273151.6
1957	5	12	12	0	100000.0	43925.9	473.7	326758.9
1957	5	13	12	0	32000.0	60000.0	476.0	354600.8
1957	5	14	12	0	40000.0	42370.2	473.5	324300.8
1957	5	15	12	0	65000.0	50051.1	474.5	336436.9
1957	5	16	12	0	44000.0	53444.6	475.0	341798.8
1957	5	17	12	0	38000.0	43680.2	473.7	326370.6
1957	5	18	12	0	41000.0	40354.8	473.2	321116.4
1957	5	19	12	0	42000.0	41213.0	473.3	322472.4
1957	5	20	12	0	35000.0	39098.5	473.0	319131.4
1957	5	21	12	0	37000.0	36767.5	472.7	315066.1
1957	5	22	12	0	40000.0	37937.1	472.9	317138.4
1957	5	23	12	0	40000.0	39361.4	473.1	319546.8
1957	5	24	12	0	45000.0	41726.2	473.4	323283.3
1957	5	25	12	0	48000.0	45339.6	473.9	328992.5
1957	5	26	12	0	50000.0	48024.4	474.2	333234.7
1957	5	27	12	0	75000.0	59300.0	475.7	350308.6
1957	5	28	12	0	54000.0	60000.0	476.5	359928.3
1957	5	29	12	0	65000.0	60000.0	476.4	358936.5
1957	5	30	12	0	47000.0	59706.6	475.7	350896.2
1957	5	31	12	0	41000.0	47216.9	474.1	331958.8
1957	6	1	12	0	35000.0	40029.2	473.2	320602.0
1957	6	2	12	0	34000.0	35837.9	472.6	313418.9
1957	6	3	12	0	35000.0	34852.3	472.4	311672.5
1957	6	4	12	0	30000.0	33104.4	472.2	308575.4
1957	6	5	12	0	30000.0	30752.8	471.8	304408.6

Figure B7. (Sheet 5 of 6)

1957	6	6	12	0	30000.0	30087.7	471.7	303230.2
1957	6	7	12	0	28000.0	29206.6	471.6	301668.9
1957	6	8	12	0	25000.0	27229.6	471.3	298165.8
1957	6	9	12	0	18000.0	23277.6	470.6	290535.8
1957	6	10	12	0	16000.0	19021.7	469.9	281986.7
1957	6	11	12	0	16000.0	16721.1	469.5	278274.9
1957	6	12	12	0	15000.0	15678.7	469.3	276593.0
1957	6	13	12	0	9000.0	12985.2	468.8	271834.3
1957	6	14	12	0	7000.0	9680.5	468.1	265010.5
1957	6	15	12	0	8000.0	8198.0	467.7	261949.2
1957	6	16	12	0	5000.0	7003.9	467.5	259483.4
1957	6	17	12	0	4000.0	5361.9	467.1	256092.8
1957	6	18	12	0	5000.0	4798.1	466.9	254674.0
1957	6	19	12	0	7000.0	5492.6	467.1	256362.6
1957	6	20	12	0	5000.0	5730.3	467.2	256853.5
1957	6	21	12	0	5000.0	5179.9	467.1	255716.9
1957	6	22	12	0	5000.0	4972.4	467.0	255288.6

Figure B7. (Sheet 6 of 6)

18. This example simulates a dam breach and computes the resulting outflow hydrograph.

Example 8
Dam Breach Simulation


```
ID Example 8
ID Dam Breach Simulation
ID
IO 1 0
KK Teton
CG .0019 .08 1 3
CE 5030 5040 5440
CT 0 800 2000
ON 1 5000 5500 2
EL 5000 5500
DC 0 0
SN 8
SE 5040 5075 5100 5150 5200 5250 5300 5320
SV 500 750 17500 51000 102000 167000 249000 286000
IC 1 5302 .25 10
HN 10 2 1 1 87 1200
HI 3580 3580
DB 5302 5302 0 5040 500 0 1 0 0 79200
DB 0
ZZ
```

 The Units are English

KK Teton

Outflow Rating Curves

 Outflow Structure Number 1 is an Input Elevation Vs Discharge

			Outflow Structure			
Elevation	1	2	3	4	5	Total
5000.00	0.00	0.00	0.00	0.00	0.00	0.00
5500.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure B8. RESOUT output for example problem 8 (Continued)

Output Hydrograph for Reservoir: Teton

Year	Mo	Dy	Hour	Inflow	Outflow	Elevation	Storage
87	1	1	12 0	3580.0	0.0	5302.0	252700.0
87	1	1	1215	3580.0	200360.4	5300.9	250703.7
87	1	1	1230	3580.0	1047237.0	5293.2	237890.0
87	1	1	1245	3580.0	2476723.0	5271.1	201559.3
87	1	1	13 0	3580.0	3247776.0	5226.7	136667.7
87	1	1	1315	3580.0	2872622.0	5215.0	121500.6
87	1	1	1330	3580.0	1857246.0	5180.0	81600.5
87	1	1	1345	3580.0	976069.0	5142.6	46062.7
87	1	1	14 0	3580.0	768795.2	5131.9	38856.6
87	1	1	1415	3580.0	690911.3	5127.5	35925.3

Figure B8. (Concluded)

APPENDIX C: DEFINITION OF VARIABLES

A
Area of the pipe used in the outlet works subroutine.

ABTRAD
Radius, in feet or metres, of the adjacent section if concrete is used in the uncontrolled ogee subroutine.

ADSCTM
Flag to indicate the material in the adjacent sections (1 = concrete, 2 - earthen) as used in the uncontrolled ogee subroutine.

APDPTH
Approach depth, in feet or metres, as required in the drop inlet subroutine and in the uncontrolled ogee subroutine.

APWDTH
Width of the approach channel, in feet or metres, as used in the uncontrolled ogee subroutine.

AREAIN
Incremental area added to the AREAT in the tailwater subroutine used to determine the actual area for a given flow.

AREAT
Total area used in determining the tailwater depth in the tailwater depth subroutine.

B
Base width of the trapezoid formed by the incremental depth and top width in determining the actual tailwater depth using Manning's equation.

BASELV
Lower bounds for computation of rating curves, in feet or metres.

BD
Reservoir width, in feet or metres, at the dam as used in the uncontrolled broad-crested weir subroutine.

BLKNM
Block name for the structure, limited to 40 characters.

BOBELV
Bottom of the breach elevation used in the dam breach calculations, in feet or metres.

BOUNDS (I)
Upper and lower (I-1 and I-2) bounds used when a solution is converged upon using the bisection method of convergence.

BRCHCT
Number of time steps that have occurred since the dam breach began.

BREL
Instantaneous breach elevation used in the dam breach subroutine.

BRWDTH
Instantaneous width of the breach used in the dam breach subroutine.

CB1	Weir coefficient used for the horizontal section of the breach and overflow section of the dam.
CB2	Weir coefficient used for the triangular section of the breach section of the dam.
CE (I)	Channel elevations of downstream channel corresponding to channel top widths, in feet or metres. Limited to 20 points.
CHANEL (I)	Downstream channel elevation array to be used in conjunction with a user-specified elevation-versus-discharge curve in feet or metres. Limited to 100 points.
CHANQ (I)	Downstream channel discharge array to be used in conjunction with a user-specified elevation-versus-discharge curve in cubic feet per second or cubic metres per second. Limited to 100 points.
CIHY	Current time inflow hydrograph value (corresponds to CTM).
CKA (I,J)	Array containing the relationship between He/R and abutment contraction coefficient for uncontrolled ogee spillways with adjacent concrete sections.
CO	Circular crest coefficient as used in the drop inlet subroutine.
COARA (I,J)	Array that contains the relationship between the circular crest coefficient to approach depth/radius for different approach depths. It is used in the drop inlet subroutine.
COESUB	Submergence coefficient as input to the uncontrolled ogee subroutine.
CONV	Conversion factors used throughout the program. They are dependent on whether the units are English or metric.
CRDCK	Two-character ID used to check card sequencing.
CRDID	Temporary location used to store the first two letters of an input record.
CRSTEL	Crest elevation of either the tainter gate or the vertical lift gate.
CRSTHT	Height of the spillway crest above the approach apron as used in the uncontrolled ogee subroutine.
CRSTWD	Width of the crest, in feet or metres, in the uncontrolled broad-crested weir subroutine.

CSLOPE	Downstream channel slope in feet/foot or metres/metre.
CT (I)	Channel top widths of downstream channel corresponding to channel elevations in feet or metres. Limited to 20 points.
CTM	Current time since the simulation began. Used in the dam breach subroutine.
CV	Coefficient for correction for velocity of approach as used in the dam breach routine and the uncontrolled broadcrested weir subroutine.
D	Pipe diameter, in feet or metres, used in the outlet works subroutine.
DC	Discharge coefficient as used in the uncontrolled ogee subroutine.
DC133 (I,J)	Array containing the relationship between He/Hd and discharge coefficient for a P/Hd of 1.33. It is used in the uncontrolled ogee spillway routine.
DC33 (I,J)	Array containing the relationship between He/Hd and discharge coefficient for a P/Hd of .33. It is used in the uncontrolled ogee spillway routine.
DC67 (I,J)	Array containing the relationship between He/Hd and discharge coefficient for a P/Hd of .67. It is used in the uncontrolled ogee spillway routine.
DESHD	Design head, in feet or metres, as used in the uncontrolled ogee subroutine.
DIFF	Difference between the upper and lower bounds used when checking convergence.
DIFF2	Difference between the upper and lower bounds used when checking convergence.
DTMO	Term 2S/t - O (2 × storage/time - outflow). Used in modified Puls subroutine.
DTPO	Term 2S/t + O (2 × storage/time + outflow). Used in modified Puls subroutine.
DW	Reservoir width, in feet or metres, at the dam used in the dam breach subroutine.
DWORMN	Flag to tell whether to use Manning's equation or the Darcy-Weisbach equation to determine the frictional loss coefficient in the outlet works subroutine.

DY	Difference between the Y1 data and the Y2 data in the double linear interpolation subroutine.
E	Absolute roughness of the pipe to be used in the Darcy-Weisbach equations in the outlet works subroutine.
ED	Absolute roughness divided by the pipe diameter (relative roughness).
EKA (I,J)A	Array containing the relationship between He/R and the abutment contraction coefficient for uncontrolled ogee spillways with adjacent earthen sections.
ELDTOP	Elevation, in feet or metres, of the downstream top of the exit portal as used in the outlet works subroutine.
ELEV	Actual distance from the bottom of the channel to the water surface.
ELEV	Array of elevations in the outlet works subroutine generated by choosing values of flow. The array is later interpolated from to determine the flows at the elevations in RE.
ELINVT	Elevation, in feet or metres, of the upstream invert as used in the outlet works subroutine.
ELOG	Conversion from log base 10 to natural log.
ELVMAX	Upper bounds for computation of rating curves, in feet or metres.
ELVSTP	Elevation step, in feet or metres, determined by (ELVMAX - BASELV)/NRTPTS.
ENGMET	English/metric flag, 0 if English units are to be used and 1 if metric units.
ESPLWD	Calculated effective spillway width, in feet or metres, as used in the uncontrolled ogee subroutine.
EVAPRT	The evaporation rate, as entered, in inches or centimetres.
EVIS	The absolute roughness divided by the kinematic viscosity as used by the outlet works routine.
F	Darcy-Weisbach frictional loss coefficient (f) in the pipe as computed by the Jeppson routine in the outlet works subroutine.
FL	Frictional length of the pipe as used in the outlet works subroutine.

FROUNO	Froude number as calculated for use in determining the outlet portal pressure in the outlet works subroutine.
FS	Square root of f as calculated by the Jeppson routine of the Darcy-Weisbach section of the outlet works subroutine.
FW	Final width of the dam breach, in feet or metres.
G	Acceleration due to gravity, set by type of units.
GATBOT	Elevation of the bottom of the gate opening as computed by the vertical lift gate subroutine.
GATWDT	Gate width of either the vertical lift gates or the tainter gates. NOTE: GATWDT is the width of one gate only.
GTSTEL	Gate seat elevation used in the vertical lift gate subroutine.
H1	Head above the bottom of the gate in the vertical lift gate subroutine.
H2	Head above the gate seat elevation in the vertical lift gate subroutine.
HDHD	Actual head on the crest divided by the design head as used in the uncontrolled ogee subroutine.
HDRS	Head on the crest divided by the radius of the drop inlet in the drop inlet subroutine.
HE	Energy head as calculated in the uncontrolled ogee subroutine.
HEAD	Resistance loss, in feet, for use in the Manning equation in the outlet works subroutine.
HEDHD	Energy head divided by the design head as used in the uncontrolled ogee subroutine.
HGUESS	Initial guess of water surface elevation as used in the Darcy-Weisbach equations in the outlet works subroutine.
HL	Head loss as computed by the Jeppson routine in the Darcy-Weisbach section of the outlet works subroutine.
ICNT2	Multiple use counter.
IDANMO	Indicator of how many days there are in a particular month as used in the output subroutine.
IDATE (I,J)	Array that keeps track of the time, day, month, and year of the outflow hydrograph as used in the output hydrograph.
IFNAM	Input file name (limited to 8 characters).
INIT	A general-use counter variable.

LCNT   Multiple-use counter.

MIN   Designates the position of the just-smaller value in the linear
                interpolation subroutine.

N   Number of reservoir storage pairs used in the subroutine to
                calculate SV, given SE and SA.

NCKAPT   Counter that indicates the number of values in the CKA array.
                It is used in the uncontrolled ogee subroutine.

NCOPT   Counter to indicate the number of values in the COARA array in
                the drop inlet subroutine.

NCSPRS   Number of cross-section pairs read in as either CE and CT or
                CHANEL and CHANQ.

NCT   Counter used to indicate the number of iterations used to con-
                verge on the solution of the smooth-flow equation of the Moody
                diagram in the Darcy-Weisbach section of the outlet works
                subroutine.

NDCPTS   Counter that indicates the number of values in the DCXX arrays
                (used in the uncontrolled ogee subroutine).

NEKAPT   Counter that indicates the number of values in the EKA array
                (used in the uncontrolled ogee subroutine).

NINPTS   Number of inflow hydrograph points.

NLOOP   Variable used to determine the number of times a read loop
                is to be executed.

NOOTST   Variable containing the number of output structures.

NOTPTS   Number of outflow hydrograph points to generate at TMSTP time
                intervals.

NPRTPR   Number of points in the portal pressure array.

NPTS   Number of points in the arrays used in the linear interpolation
                subroutines.

NRTPTS   Number of rating points to generate between the BASELV and the
                ELVMAX.

NSTPRS   Number of reservoir storage pairs to be read in.

NSUBPT   Counter that indicates the number of values in the SUBCOE array
                (used in the uncontrolled ogee subroutine).

NTEMP2   Counter to indicate the number of values in the TEMP2 array in
                the drop inlet subroutine.

NTGATE   Variable that counts the number of tainter gates that have been used (a maximum of three).

NTGTOP (I)   Number of tainter gate openings. For each of up to three tainter gates, the number of gate openings to compute rating curves for is stored here.

NVAL   Counter used to keep up with the number of values calculated that will be used for convergence by the bisection method in the uncontrolled broad-crested weir subroutine.

NVLFGT   Variable that counts the number of vertical lift gates that have been specified (maximum of three).

NVLFOP (I)   Number of vertical lift gate openings. For each of up to three vertical lift gates, the number of gate openings to compute rating curves for is stored here.

OD (I,J)   Outflow rating curve array. Up to five (J) different structures with the sum of them placed in the sixth (J) position and used as the rating curve for routing. Limited to 100 points per structure (I).

OD1   Composite outflow rating curve (column 6 in OD) used in dam breach calculation.

OFNAM   Output file name (limited to 8 characters).

OTBRCH   Reservoir outflow due to the breach.

OTHY (I)   Outflow hydrograph points from any routing method, in cubic feet per second or cubic metres per second. Limited to 100 points.

OTSTR   Outflow of the reservoir due to the outlet structures. Used in the dam breach subroutine.

OTSTTY (I)   Output structure type array. Contains the name of each of the five (I) chosen output structures.

OTWEIR   Outflow due to weir flow in the overtopping of the dam in the dam breach subroutine.

OUT   Reservoir outflow due to both the dam breach and the outlet structures. Used in the dam breach subroutine.

OUTLST   String variable used to echo the input data file to the output field if requested.

PAR   Equation eV (f/8)/(kinematic viscosity) which is used as a check to determine if the pipe is wholly rough. It is used in the Darcy-Weisbach section of the outlet works subroutine.

PDHD   Crest height divided by the design head as used in the uncontrolled ogee subroutine.

PDRS	Approach depth divided by the radius of the drop inlet in the drop inlet subroutine.
PIERNO	Number of piers as used in the uncontrolled ogee subroutine.
PIERTY	Type of piers as defined by EM 1110-2-1603, III-11, as used in the uncontrolled ogee subroutine.
PIHY	Previous time inflow hydrograph value (corresponds to PTM).
PORTPR	Exit portal pressure array containing numerically digitized data from the curves in EM 1110-2-1602, App. III, Figure III-5.
PRTFLG	Print flag. Set to 1 if input data are to be echoed to output file.
PSUB	Submergence coefficient as used in the uncontrolled ogee subroutine.
PTM	Previous time. Used in the dam breach subroutine.
Q	Flow, in cubic feet per second or cubic metres per second, used in the tailwater computation subroutine. Also used as an array containing the upper and lower bounds to be tested for convergence to a solution in the uncontrolled broad-crested weir subroutine and the uncontrolled ogee subroutine.
RADIUS	Radius, in feet or metres, of the drop inlet in the drop inlet subroutine.
RE (I)	Reservoir elevation array. Array containing the elevations computed from the given minimum and maximum elevations and number of included divisions, in feet or metres. Limited to 100 points.
REY	Reynolds number, as calculated and used in the Darcy-Weisbach section of the outlet works subroutine.
RIHY (I)	Inflow hydrograph array. Limited to 100 points.
RIHYT (I)	Inflow hydrograph time array. Value at the end of each timestep is computed from the time step entered. Limited to 100 points.
RISM	Sum of the current and previous inflow hydrograph points. Used in the modified Puls subroutine and the dam breach subroutine until the breach elevation is reached.
RIW	Initial width of the dam breach, in feet or metres.
RK	Sum of any other minor loss coefficients to be used in the outlet works subroutine.

RKA   Abutment contraction coefficient as used in the uncontrolled
                       ogee subroutine.

RKNWN   Known values of an equation. The actual contents vary by
                       usage.

RKP   Pier contraction coefficient as used in the uncontrolled ogee
                       subroutine.

RKPARA (I,J)   Array containing the relationship between H/Hd and pier con-
                       traction coefficient for uncontrolled ogee spillways.

RKS   Submergence correction for tailwater effects on weir outflow.

RKSCHK   Flag used to calculate which equation to use in the calculation
                       of the submergence correction coefficient used in the dam
                       breach subroutine.

RKSFLG   Index calculated to determine if the submergence correction
                       should be made. It is used in the uncontrolled ogee spillway
                       routine.

RKTOT   Value for K_f as computed using the Manning equation in the out-
                       let works subroutine.

RLFTSD   Left side of the dam breach equations used to determine
                       convergence.

RLPYR   Indicator to determine if the year given is a leap year or not,
                       as used in the output subroutine.

RMANN   Manning's N of downstream channel.

RMAXFL   Maximum downstream channel capacity or release to be main-
                       tained, in cubic feet per second or cubic metres per second.
                       Used in the modified Puls subroutine.

RMNFCT   Conversion factor used in Manning's equation that is set based
                       on whether the units are English or metric.

RTFLG   Routing flag. Set to 1 if a routing was done. Used to deter-
                       mine if outflow hydrograph is to be printed.

RTSDE   The right side of the dam breach equations used to determine
                       convergence.

RYR   Year, as used in the output subroutine.

SA (I)   Reservoir surface areas corresponding to reservoir storage
                       elevations, in acres or hectares. Limited to 100 points.

SE (I)   Reservoir storage elevations corresponding to reservoir storage
                       volumes, in feet or metres. Limited to 100 points.

SLOPE   First best guess of the slope of the energy line to get an initial solution for the Manning equation in the outlet works subroutine.

SLP   Side slope of the channel segment used for determining the actual tailwater depth.

SLPFCC   Slope face correction factor for non-vertical approach slopes as used in the uncontrolled ogee subroutine.

SPLNW   Net length of the spillway, in feet or metres, excluding the total pier width as used in the uncontrolled ogee subroutine.

STDY   Starting day of the month.

STMN   Starting month of the year.

STOR1   Storage at the beginning of the current time period. Used in the modified Puls subroutine and the dam breach subroutine until the breach elevation is reached.

STOR2   Storage at the end of the current time period. Used in the modified Puls subroutine and the dam breach subroutine until the breach elevation is reached.

STORGE   Value of storage as printed out in the output subroutine.

STTM   Starting time of day (24-hour format).

STYR   Starting year (two digits).

SUBCLM (I,J)   Array containing the relationships defining the submergence coefficient boundary values for uncontrolled ogee spillways.

SUBCOE (I,J)   Array containing the relationships defining the submergence coefficients for uncontrolled ogee spillways.

SV (I)   Reservoir storage volume corresponding to reservoir storage elevations in acre-feet or 1,000 cubic metres. Limited to 100 points.

TARA (I)   Temporary array used to input 10 values from disk input files.

TELEV   Temporary elevation of the water surface used in the dam breach and outlet works subroutines.

TEMP (I,J)   Temporary use array used for multiple purposes throughout the program.

TEMP2 (I,J)   Array containing the bounds for the curves defined by COARA in the drop inlet subroutine.

TGATOD(I,J,K)   Tainter gate outflow rating curve array. Allows up to three (I) tainter gates each with up to 99 points calculated (J) for each of 10 (K) gate openings. The values correspond to those in the reservoir elevation array.

TGTEL (I,J)   Tainter gate elevation at which orifice flow occurs for that tainter gate (I) and that gate opening (J).

TGTLBL   A character label used to check for the use of tainter gates in the output subroutine.

TGTOPS(I,J,K)   Tainter gate opening array. For each of a maximum of three (I) different tainter gates, there can be up to 10 (J) openings each having associated with them an opening size in feet or metres (K=1) and a coefficient C (K=2).

TGTUSE (I)   Tainter gate opening to use in routing, in feet or metres. Limited to one per structure and three different tainter gates.

TITLE (I)   The three (I) lines, each 78 characters long, set aside for the problem title.

TMINC   Time increment used for inflow hydrograph points, in hours.

TMMAX   Time to reach maximum dam breach size, in hours.

TMSTP   Time step, in hours, associated with the generation of the outflow hydrograph.

TOBELV   Top of the breach elevation used in the dam breach calculations, in feet or metres.

TODELV   Top of dam elevation, in feet or metres, associated with modified Puls routing.

TOTEVP   Total evaporation, in acre-feet or hectare-metres, as calculated for the average surface area.

TQ   Initial, temporary value of the outflow as generated using the value of SLOPE and Manning's equation in the outlet works subroutine.

TSTRNG   Temporary string variable used to read all but the record ID. Used in the data input subroutine.

TWCFLG   Flag used to signal if channel input is a set of CE versus CT or elevation versus discharge.

TWD   Tailwater depth, as calculated by the tailwater subroutine using Manning's equation or the input elevation-versus-discharge relationship.

UNIT   A character label used to print out the appropriate units, in feet or metres.

UNKWNS   Unknown values of an equation used to compare to the knowns, RKNWN, for use in determining the actual values using the bisection method of convergence.

V   Velocity, as used in Manning's equation, in the outlet works subroutine.

VAL   Interpolated value returned from the double linear interpolation subroutine.

VIS   Kinematic viscosity X 10^5 of the fluid in question, as used in the outlet works subroutine.

VLFCOR   Correction to flow for the presence of the vertical lift gate over weir flow.

VLFEL (I,J)   Vertical lift gate elevation at which orifice flow occurs for that vertical lift gate (I) and that gate opening (J).

VLFLBL   Character label used to check for the use of vertical lift gates in the output subroutine.

VLFOPS(I,J,K)   Vertical lift gate opening array. For each of a maximum of three (I) different vertical lift gates, there can be up to 10 (J) openings, each having associated with them an opening size in feet or metres (K=1) and a coefficient C (K=2).

VLFTOD(I,J,K)   Vertical lift gate outflow rating curve array. Allows up to three (I) vertical lift gates each with up to 99 points calculated (J) for each of 10 (K) gate openings. The values correspond to those in the reservoir elevation array.

VLFUSE (I)   Vertical lift gate opening to use in routing, in feet or metres. Limited to one per structure and three different vertical lift gates.

WEIRL   The length of the dam that is actually overtopped. Used in the dam breach subroutine.

WETPER   Wetted perimeter, in feet or metres, as used in the outlet works subroutine.

WSEL (I)   Water surface elevations computed when routing an inflow hydrograph by any method, in feet or metres. Limited to 100 points.

X   The X range used in the linear interpolation subroutine. Also used as the X value to locate in the double linear interpolation subroutine.

X1   The first X range used in the double linear interpolation subroutine.

X2   The second X range used in the double linear interpolation subroutine.

XLUP   The X value to look up using the linear interpolation
                subroutine.

Y   The Y range used in the linear interpolation subroutine. Also
                used as the Y value to locate in the double linear interpola-
                tion subroutine.

Y1   The first Y range used in the double linear interpolation
                subroutine.

Y2   The second Y range used in the double linear interpolation
                subroutine.

YDD   The value of Y_d/D in the outlet works subroutine.

YINC   The Y value to locate in the double linear interpolation
                subroutine.

YNEW   The interpolated value returned from the linear interpolation
                subroutine.

Z   Side slope of the dam breach, in feet (metres) horizontal to
                1 foot (0.3048 metre) vertical.

```
C
C Reservoir Routing Program with Outlet Structures
C Created by: Stuart T. Purvis
C At: Texas A&M University
C
      DIMENSION RIHY(100),TARA(10),SV(100),SE(100),SA(100),
     10D(100,6),WSEL(100),OTHY(100),CE(20),CT(20),RIHYT(100),
     2RE(100),TGATOD(3,100,10),TGTEL(3,10),TGTOPS(3,10,2),
     3TGTUSE(3),NTGTOP(3),VLFTOD(3,100,10),VLFEL(3,10),VLFOPS(3,10,2),
     4VLFUSE(3),NVLFOP(3),CHANEL(100),CHANQ(100),TEMP(100,2)
      CHARACTER*78 TITLE(3),IFNAM*8,OFNAM*8,CRDID*2
      CHARACTER*40 BLKNM,OTSTTY(5)
C
C Sets the initial conditions in reservoir data to be tested for later.
C
      DO 100 I=1,5
         SV(I)=-1.0
         SE(I)=-1.0
         SA(I)=-1.0
         CHANEL(I)=0.
         TARA(I)=0.0
         TARA(I+5)=0.0
 100  CONTINUE
      DO 103 I=1,3
 103  TGTOPS(I,1,1)=0.
      DO 106 I=1,100
         DO 107 J=1,6
            OD(I,J)=0.
 107     CONTINUE
         RIHY(I)=0.
 106  CONTINUE
      PRTFLG=0.
      RTFLG=0.
      ENGMET=0.
      NOUT=6
      CALL TITEPT (TITLE,NOUT)
      WRITE (6,900)
      READ (5,920) IFNAM
      OPEN (UNIT=1,FILE=IFNAM,STATUS='OLD',ACCESS='SEQUENTIAL',FORM=
     1'FORMATTED',BLANK='NULL')
      WRITE (6,910)
      READ (5,920) OFNAM
      OPEN (UNIT=2,FILE=OFNAM,STATUS='UNKNOWN',ACCESS='SEQUENTIAL',
     1FORM='FORMATTED',BLANK='NULL')
      OPEN (UNIT=3,STATUS='SCRATCH',ACCESS='SEQUENTIAL',FORM=
     1'FORMATTED',BLANK='NULL')
      NOUT=2
      CALL TITEPT (TITLE,NOUT)
      DO 110 I=1,3
```

```
      READ (1,930) CRDID,TITLE(I)
      IF (CRDID.NE.'ID') CALL ERR(CRDID)
      WRITE (2,960) TITLE(I)
110   CONTINUE
      WRITE (2,990)
      WRITE (2,*)
      CALL RDIN (TARA,CRDID)
      IF (CRDID.NE.'IO') CALL ERR(CRDID)
      PRTFLG=TARA(1)
      IF (PRTFLG.EQ.1.) CALL LISTOT
      WRITE (2,*)
      ENGMET=TARA(2)
      IF (ENGMET.EQ.0) THEN
          WRITE (2,970)
      ELSE
          WRITE (2,980)
      END IF
      WRITE (2,*)
      READ (1,940) CRDID,BLKNM
      IF (CRDID.NE.'KK') CALL ERR(CRDID)
      WRITE (2,940) CRDID,BLKNM
      CALL RDIN(TARA,CRDID)
      IF(CRDID.NE.'CG') CALL ERR(CRDID)
      CALL CHANIN (TARA,CSLOPE,RMANN,NCSPRS,CE,CT,CHANEL,CHANQ)
      CALL OTFLW(RE,OD,CSLOPE,RMANN,NCSPRS,CE,CT,TGTUSE,ENGMET,
     1OTSTTY,TGATOD,TGTEL,TGTOPS,NRTPTS,NOOTST,NTGTOP,NTGATE,
     2VLFTOD,VLFEL,VLFOPS,VLFUSE,NVLFOP,NVLFGT,CHANEL,CHANQ)
      CALL RDIN(TARA,CRDID)
      IF (CRDID.EQ.'ZZ') THEN
          RTFLG=1.
          GOTO 180
      END IF
      IF (CRDID.NE.'SN') CALL ERR(CRDID)
      NSTPRS=TARA(1)
      NLOOP=(TARA(1)/10.)+.9
      LCNT=0
      DO 190 K=1,4
          ICNT2=1
          LCNT=LCNT+1
          DO 130 I=1,NLOOP
              CALL RDIN(TARA,CRDID)
              IF(CRDID.NE.'SV'.AND.CRDID.NE.'SE'.AND.CRDID.NE.'SA')
     1        GOTO 200
              IF (CRDID.EQ.'SV') THEN
                  DO 140 J=ICNT2,ICNT2+9
140               SV(J)=TARA(J-ICNT2+1)
                  ICNT2=ICNT2+10
              END IF
              IF (CRDID.EQ.'SE') THEN
                  DO 150 J=ICNT2,ICNT2+9
150               SE(J)=TARA(J-ICNT2+1)
                  ICNT2=ICNT2+10
              END IF
              IF (CRDID.EQ.'SA') THEN
                  DO 160 J=ICNT2,ICNT2+9
```

D2

```
160           SA(J)-TARA(J-ICNT2+1)
              ICNT2-ICNT2+10
           END IF
130     CONTINUE
190  CONTINUE
200  CONTINUE
     IF (SE(1).LT.0.OR.LCNT.EQ.1) CALL ERR(CRDID)
     IF (SV(1).LT.0.AND.SA(1).LT.0) CALL ERR(CRDID)
     IF (SV(2).LT.0) CALL SVOL(SV,SE,SA,ENGMET)
     IF (CRDID.NE.'IC') CALL ERR(CRDID)
     WSEL(1)-TARA(2)
     TMSTP-TARA(3)/24.
     NOTPTS-TARA(4)
     IF (TARA(1).EQ.2) CALL INTERP(NSTPRS,SV,SE,TARA(2),WSEL(1))
     CALL RDIN(TARA,CRDID)
     IF (CRDID.NE.'HN') CALL ERR(CRDID)
     TMINC-TARA(1)/24.
     NINPTS-TARA(2)
     STDY-TARA(3)
     STMN-TARA(4)
     STYR-TARA(5)
     STTM-TARA(6)
     NLOOP-(TARA(2)/10.)+.9
     TEMP(1,1)-0.
     DO 115 I-1,NINPTS-1
        TEMP(I+1,1)-I*TMINC
115  CONTINUE
     ICNT2-1
     DO 120 I-1,NLOOP
        CALL RDIN(TEMP(ICNT2,2),CRDID)
        IF (CRDID.NE.'HI') CALL ERR(CRDID)
        ICNT2-ICNT2+10
120  CONTINUE
     RIHYT(1)-0.
     RIHY(1)-TEMP(1,2)
     DO 116 I-2,NOTPTS
        RIHYT(I)-(I-1)*TMSTP
        IF ((I-1)*TMSTP.LE.TEMP(NINPTS,1)) THEN
           CALL INTERP(NINPTS,TEMP(1,1),TEMP(1,2),RIHYT(I),RIHY(I))
        ELSE
           RIHY(I)-TEMP(NINPTS,1)
        END IF
116  CONTINUE
     CALL RDIN (TARA,CRDID)
     IF (CRDID.EQ.'DB'.OR.CRDID.EQ.'DD') THEN
        CALL BREACH (TARA,WSEL,SV,SE,NINPTS,OTHY,NSTPRS,OD(1,6),
   1    RIHY,CSLOPE,RMANN,NCSPRS,CE,CT,CB1,CB2,ENGMET,RIHYT,
   2    NOTPTS,TMSTP,TMINC,NRTPTS,RE,CHANEL,CHANQ,SA,CRDID)
     ELSE
        CALL PULS(NINPTS,NSTPRS,SV,SE,OD(1,6),TMINC,RIHY,OTHY,
   2    WSEL,ENGMET,NOTPTS,TMSTP,RIHYT,NRTPTS,RE,CRDID,TARA)
     END IF
```

```
  180  CONTINUE
       CALL OUTPUT(OTHY,NINPTS,STDY,STMN,STYR,STTM,TMINC,BLKNM,
      1WSEL,NOTPTS,TMSTP,OTSTTY,TGATOD,TGTEL,TGTOPS,OD,NRTPTS,RTFLG,
      2NOOTST,NTGTOP,ENGMET,NTGATE,TGTUSE,RE,VLFTOD,VLFEL,VLFOPS,
      3VLFUSE,NVLFOP,NVLFGT,RIHY,NSTPRS,SE,SV)
       CLOSE (UNIT=1)
       CLOSE (UNIT=2)
       CLOSE (UNIT=3)
       STOP
  900  FORMAT (15HINPUT FILENAME?)
  910  FORMAT (16HOUTPUT FILENAME?)
  920  FORMAT (A8)
  930  FORMAT (A2,A78)
  940  FORMAT (A2,A40)
  950  FORMAT (10F8.0)
  960  FORMAT (A78)
  970  FORMAT (22H The Units are English)
  980  FORMAT (21H The Units are Metric)
  990  FORMAT ('1')
       END
C
C Title Subroutine
C
       SUBROUTINE TITEPT (TITLE,NOUT)
       CHARACTER*78 TITLE(3)
       IF (NOUT.EQ.6) THEN
          ICNT2=2
          ICNT3=2
       ELSE
          ICNT2=20
          ICNT3=21
       END IF
       DO 100 J=1,ICNT2
  100  WRITE (NOUT,*)
       WRITE (NOUT,900)
       WRITE (NOUT,910)
       WRITE (NOUT,920)
       WRITE (NOUT,930)
       WRITE (NOUT,940)
       WRITE (NOUT,950)
       WRITE (NOUT,960)
       WRITE (NOUT,*)
       IF (NOUT.NE.6) WRITE (NOUT,*)
       WRITE (NOUT,970)
       IF (NOUT.NE.6) WRITE (NOUT,*)
       WRITE (NOUT,980)
       IF (NOUT.NE.6) WRITE (NOUT,*)
       WRITE (NOUT,985)
       IF (NOUT.NE.6) WRITE (NOUT,*)
       WRITE (NOUT,990)
       WRITE (NOUT,1000)
       IF (NOUT.NE.6) WRITE (NOUT,*)
       WRITE (NOUT,1010)
```

```fortran
      .WRITE (NOUT,1020)
      IF (NOUT.NE.6) WRITE (NOUT,*)
      WRITE (NOUT,1030)
      IF (NOUT.NE.6) WRITE (NOUT,*)
      WRITE (NOUT,1040)
      WRITE (NOUT,1050)
      DO 110 I=1,ICNT3
      WRITE (NOUT,*)
  110 CONTINUE
      RETURN
  900 FORMAT (' ',17X,'XXXXX XXXXX XXXXX XXXXX X   X XXXXX')
  910 FORMAT (' ',17X,'X   X X     X       X   X X X X   X ')
  920 FORMAT (' ',17X,'X   X X     X       X   X X X X   X ')
  930 FORMAT (' ',17X,'XXXXX XXXX  XXXXX X   X X X X   X ')
  940 FORMAT (' ',17X,'X X   X         X X X X X X   X ')
  950 FORMAT (' ',17X,'X  X  X         X X X X X X   X ')
  960 FORMAT (' ',17X,'X   X XXXXX XXXXX XXXXX XXXXX   X ')
  970 FORMAT (' ',25X,'Reservoir Outflow Model')
  980 FORMAT (' ',31X,'Developed')
  985 FORMAT (' ',34X,'by')
  990 FORMAT (' ',28X,'Stuart T. Purvis')
 1000 FORMAT (' ',29X,'Ralph A. Wurbs')
 1010 FORMAT (' ',22X,'Civil Engineering Department')
 1020 FORMAT (' ',26X,'Texas A&M University')
 1030 FORMAT (' ',34X,'for')
 1040 FORMAT (' ',21X,'Environmental Systems Divison')
 1050 FORMAT (' ',12X,'U.S. Army Engineer Waterways Experiment Station')
      END
C
C Tailwater Computation Subroutine
C
      SUBROUTINE TWATER(CSLOPE,RMANN,NCSPRS,CE,CT,Q,TWD,
     1CHANEL,CHANQ,ENGMET)
      DIMENSION CE(20),CT(20),BOUNDS(2),CHANEL(100),CHANQ(100)
      IF (CHANEL(2).NE.0.) THEN
         CALL INTERP (NCSPRS,CHANQ,CHANEL,Q,TWD)
         CE(1)=CHANEL(1)
         RETURN
      END IF
      IF (ENGMET.EQ.0.) THEN
         RKNWN=(Q*RMANN/1.486)/(CSLOPE**.5)
      ELSE
         RKNWN=(Q*RMANN)/(CSLOPE**.5)
      END IF
      AREAT=0
      DO 110 I=1,NCSPRS-1
         AREAIN=.5*(CT(I)+CT(I+1))*(CE(I+1)-CE(I))
         AREAT=AREAT+AREAIN
         UNKWNS=(AREAT**(5./3.))/(CT(I+1)**(2./3.))
         IF (RKNWN.GT.UNKWNS) GOTO 110
         IF (CT(I+1)-CT(I).GT.0.) THEN
            SLP=(CE(I+1)-CE(I))/(CT(I+1)-CT(I))
         ELSE
```

```fortran
            SLP=1.
        END IF
        BOUNDS(2)=CE(I+1)-CE(I)
        BOUNDS(1)=0
        ELEV=((CE(I+1)+CE(I))/2.)-CE(I)
        AREAT=AREAT-AREAIN
        LCNT=0
120     CONTINUE
        LCNT=LCNT+1
        B=CT(I)+ELEV*(1/SLP)
        AREAIN=.5*(CT(I)+B)*ELEV
        AREAT=AREAT+AREAIN
        UNKWNS=(AREAT**(5./3.))/(B**(2./3.))
        DIFF2=ABS(BOUNDS(1)-BOUNDS(2))
        IF (DIFF2.LT..01.OR.RKNWN.EQ.UNKWNS) THEN
            TWD=CE(I)+ELEV
            GOTO 130
        END IF
        IF (LCNT.GT.500) GOTO 140
        AREAT=AREAT-AREAIN
        IF (RKNWN.LT.UNKWNS) BOUNDS(2)=ELEV
        IF (RKNWN.GT.UNKWNS) BOUNDS(1)=ELEV
        ELEV=((BOUNDS(1)+BOUNDS(2))/2.)
        GOTO 120
110     CONTINUE
        WRITE (6,900)
        WRITE (2,900)
        STOP
140     CONTINUE
        WRITE (6,910)
        WRITE (2,910)
        STOP
130     CONTINUE
        RETURN
900     FORMAT (44H**ERROR - CHANNEL ELEV. EXCEEDS INPUT VALUES)
910     FORMAT (43H**ERROR - CHANNEL ELEVATIONS ARE TOO COARSE)
        END
C
C Channel Geometry Input
C
        SUBROUTINE CHANIN(TARA,CSLOPE,RMANN,NCSPRS,CE,CT,CHANEL,CHANQ)
        DIMENSION TARA(10),CE(20),CT(20),CHANEL(100),CHANQ(100)
        CHARACTER*2 CRDID
        CSLOPE=TARA(1)
        RMANN=TARA(2)
        TWCFLG=TARA(3)
        NCSPRS=TARA(4)
        NLOOP=(NCSPRS/10.)+.9
        LCNT=0
        IF (TWCFLG.EQ.1.) THEN
130         LCNT=LCNT+1
            ICNT2=0
            DO 100 I=1,NLOOP
```

```
              CALL RDIN(TARA,CRDID)
              IF (CRDID.EQ.'CE') THEN
                 DO 110 J=1,10
  110               CE(ICNT2+J)=TARA(J)
                 ICNT2=ICNT2+10
              END IF
              IF (CRDID.EQ.'CT') THEN
                 DO 120 J=1,10
  120               CT(ICNT2+J)=TARA(J)
                 ICNT2=ICNT2+10
              END IF
              IF (ICNT2.EQ.1) CALL ERR(CRDID)
  100      CONTINUE
           IF (LCNT.EQ.1) GOTO 130
        ELSE
  170      LCNT=LCNT+1
           ICNT2=0
           DO 140 I=1,NLOOP
              CALL RDIN(TARA,CRDID)
              IF (CRDID.EQ.'EL') THEN
                 DO 150 J=1,10
  150               CHANEL(ICNT2+J)=TARA(J)
                 ICNT2=ICNT2+10
              END IF
              IF (CRDID.EQ.'DC') THEN
                 DO 160 J=1,10
  160               CHANQ(ICNT2+J)=TARA(J)
                 ICNT2=ICNT2+10
              END IF
              IF (ICNT2.EQ.1) CALL ERR(CRDID)
  140      CONTINUE
           IF (LCNT.EQ.1) GOTO 170
        END IF
        RETURN
        END
C
C Dam Breach subroutine
C
      SUBROUTINE BREACH(TARA,WSEL,SV,SE,NINPTS,OTHY,NSTPRS,OD1,RIHY,
     1CSLOPE,RMANN,NCSPRS,CE,CT,CB1,CB2,ENGMET,RIHYT,NOTPTS,
     2TMSTP,TMINC,NRTPTS,RE,CHANEL,CHANQ,SA,CRDID)
      DIMENSION TARA(10),WSEL(100),SV(100),SE(100),OTHY(100),
     1OD1(100),RIHY(100),BOUNDS(2),CE(20),CT(20),RIHYT(100),RE(100),
     2CHANEL(100),CHANQ(100),SA(100),OHLIM(100),OHLIMT(100),
     3TELV(2),TOTF(2)
      DOUBLE PRECISION OTBRCH,CV,RKS,RTSDE,RLFTSD,DIFF,BOUNDS,
     1OTWEIR,DIFF2
      CHARACTER*2 CRDID
      IF (CRDID.EQ.'DD') THEN
         EVAPRT=TARA(1)
         IF (EVAPRT.NE.0.AND.SA(2).EQ.0) THEN
            WRITE (2,900)
            CLOSE (UNIT=1)
```

D7

```
               CLOSE (UNIT-2)
               CLOSE (UNIT-3)
               STOP
            END IF
            NOHPTS-TARA(2)
            OHTMST-TARA(3)/24.
            NLOOP-(TARA(2)/10.)+.9
            DO 130 I-1,NOHPTS
               OHLIMT(I)-(I-1)*OHTMST
130         CONTINUE
            ICNT2-1
            DO 140 I-1,NLOOP
               CALL RDIN(TARA,CRDID)
               IF (CRDID.NE.'DD') CALL ERR(CRDID)
               DO 150 J-ICNT2,ICNT2+9
150               OHLIM(J)-TARA(J-ICNT2+1)
               ICNT2-ICNT2+10
140         CONTINUE
            TOBELV-0.
         ELSE
            TODELV-TARA(1)
            TOBELV-TARA(2)
            RIW-TARA(3)
            BOBELV-TARA(4)
            FW-TARA(5)
            Z-TARA(6)
            TMMAX-TARA(7)
            IF (TARA(8).LE.0) THEN
               CB1-3.1
            ELSE
               CB1-TARA(8)
            END IF
            IF (TARA(9).LE.0) THEN
               CB2-2.45
            ELSE
               CB2-TARA(9)
            END IF
            DW-TARA(10)
            CALL RDIN (TARA,CRDID)
            IF (CRDID.NE.'DB') CALL ERR (CRDID)
            EVAPRT-TARA(1)
            IF (EVAPRT.NE.0.AND.SA(2).EQ.0) THEN
               WRITE (2,900)
               CLOSE (UNIT-1)
               CLOSE (UNIT-2)
               CLOSE (UNIT-3)
               STOP
            END IF
         END IF
         BRCHCT-0
         BREL-TOBELV
         OTBRCH-0.
         OTWEIR-0.
```

```fortran
      IF (ENGMET.EQ.1) THEN
         CONV-1000.
         CONV2-10.
      ELSE
         CONV-43560.
         CONV2-12.
      END IF
      CALL INTERP(NRTPTS,RE,OD1,WSEL(1),OTHY(1))
      IF (CRDID.EQ.'DD') THEN
         IF (OTHY(1).GT.OHLIM(1)) OTHY(1)-OHLIM(1)
      END IF
      DO 110 I-2,NOTPTS
         ICNT1-1
         CTM-(I-1)*TMSTP
         IF (CTM.LT.0.) CTM-0.
         PTM-(I-2)*TMSTP
         IF (PTM.LT.0.) PTM-0.
         CALL INTERP(NOTPTS,RIHYT,RIHY,CTM,CIHY)
         CALL INTERP(NOTPTS,RIHYT,RIHY,PTM,PIHY)
         RISM-CIHY+PIHY
         CALL INTERP(NSTPRS,SE,SV,WSEL(I-1),STOR1)
         RLFTSD-((TMSTP*86400.)*(RISM-OTHY(I-1)))/CONV+2.*STOR1
         BOUNDS(2)-SE(NSTPRS)
         BOUNDS(1)-SE(1)
         TELEV-(BOUNDS(1)+BOUNDS(2))/2.
120      CONTINUE
         IF (CRDID.NE.'DD') THEN
            IF (TELEV.GE.TOBELV.AND.I.EQ.2) BRCHCT-1.
            IF (TELEV.LE.TOBELV.AND.I.EQ.1) BRCHCT-0.
            IF (TELEV.GE.BREL) THEN
               BREL-TOBELV-BRCHCT*((TODELV-BOBELV)/(TMMAX/24.))*TMSTP
            END IF
            IF (BREL.LT.BOBELV) BREL-BOBELV
            BRWDTH-RIW+BRCHCT*((FW-RIW)/(TMMAX/24.))*TMSTP
            IF (BRWDTH.GT.FW) BRWDTH-FW
         END IF
         IF (EVAPRT.NE.0.) THEN
            CALL INTERP (NSTPRS,SE,SA,WSEL(I-1),AREA1)
            CALL INTERP (NSTPRS,SE,SA,TELEV,AREA2)
            AVAREA-(AREA1+AREA2)/2.
            TOTEVP-AVAREA*EVAPRT/CONV2
         ELSE
            TOTEVP-0.
         END IF
         CALL INTERP(NSTPRS,SE,SV,TELEV,STOR2)
         STOR2-STOR2-TOTEVP
         CALL INTERP(NSTPRS,SV,SE,STOR2,TELEV)
         CALL INTERP(NRTPTS,RE,OD1,TELEV,OTSTR)
         IF (TELEV.GE.BREL.AND.CRDID.EQ.'DB') THEN
            IF (OTBRCH.LT.0.) OTBRCH-0.
            OUT-OTSTR+OTBRCH
            CALL TWATER (CSLOPE,RMANN,NCSPRS,CE,CT,OUT,TWD,
     1      CHANEL,CHANQ,ENGMET)
```

```
        IF (TELEV-BREL.GT.0.) THEN
            RKSCHK=(TWD-BREL)/(TELEV-BREL)
        ELSE
            RKSCHK=0.
        END IF
        IF(RKSCHK.LT.0.67) THEN
            RKS=1.
        ELSE
            RKS=1.0-27.8*(((TWD-BREL)/(TELEV-BREL))-0.67)**3.
        END IF
        CV=1.0+0.023*(OUT**2.)/((DW**2.)*((TELEV-BOBELV)**2.)*
1       (TELEV-BREL))
        OTBRCH=CB1*CV*RKS*BRWDTH*(TELEV-BREL)**1.5+CB2*CV*RKS*Z
1       *(TELEV-BREL)**2.5
        WEIRL=DW-BRWDTH-2.*(TODELV-BREL)*Z
        IF (TELEV-TODELV.LE.0.OR.BOBELV.EQ.TODELV) THEN
            OTWEIR=0
        ELSE
            OTWEIR=CB1*WEIRL*(TELEV-TODELV)**1.5
        END IF
    ELSE
        OTBRCH=0.
        OTWEIR=0.
    END IF
    RTSDE=2.*STOR2+((TMSTP*86400.)*(OTSTR+OTBRCH+OTWEIR))/CONV
    DIFF=ABS(RTSDE-RLFTSD)
    IF (ICNT1.EQ.1) THEN
        TELV(1)=TELEV
        TOTF(1)=OTBRCH
    END IF
    IF (DIFF.LT.1.5 OR.(TELV(1)-TELEV.EQ.0.AND.ICNT1.GT.2)) THEN
        IF (TELV(1)-TELEV.EQ.0.AND.ICNT1.GT.2) THEN
            WSEL(I)=(TELV(1)+a·ELV(2))/2.
            IF (CRDID.EQ.'DD') THEN
                CALL INTERP(NRTPTS,RE,OD1,WSEL(I),OTHY(I))
            ELSE
                OTBRCH=(TOTF(1)+a·OTF(2))/2.
                OTHY(I)=OTSTR+OTBRCH+OTWEIR
            END IF
        ELSE
            WSEL(I)=TELEV
            OTHY(I)=OTSTR+OTBRCH+OTWEIR
        END IF
        IF (CRDID.EQ.'DD') THEN
            IF (CTM.GT.OHLIMT(NOHPTS)) THEN
                RMAXFL=OHLIM(NOHPTS)
            ELSE
                CALL INTERP(NOHPTS,OHLIMT,OHLIM,CTM,RMAXFL)
            END IF
            IF (OTHY(I).GT.RMAXFL) THEN
                OTHY(I)=RMAXFL
                STOR2=(((.5*(TMSTP*86400.)*(RISM-OTHY(I-1)-
1               OTHY(I))))/CONV+STOR1)
```

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                   IF (STOR2.GT.SV(NSTPRS)) THEN
                      WRITE (2,910)
                      CLOSE (UNIT-1)
                      CLOSE (UNIT-2)
                      CLOSE (UNIT-3)
                   END IF
                   CALL INTERP(NSTPRS,SV,SE,STOR2,WSEL(I))
                END IF
             END IF
             IF (BRCHCT.GE.1.) BRCHCT-BRCHCT+1
             GOTO 110
          END IF
          IF (RTSDE.LT.RLFTSD) BOUNDS(1)-TELEV
          IF (RTSDE.GE.RLFTSD) BOUNDS(2)-TELEV
          TELEV-(BOUNDS(1)+BOUNDS(2))/2.
          GOTO 120
  110   CONTINUE
        RETURN
  900   FORMAT (' **ERROR** In order to use evaporation, surface area',
      1' must be given')
  910   FORMAT (' **ERROR** Reservoir storage required exceeds values',
      1' supplied')
        END
C
C Modified Puls routing subroutine
C
        SUBROUTINE PULS(NINPTS,NSTPRS,SV,SE,OD1,TMINC,RIHY,OTHY,WSEL,
      1ENGMET,NOTPTS,TMSTP,RIHYT,NRTPTS,RE,CRDID,TARA)
        DIMENSION SV(100),SE(100),OD1(100),RIHY(100),OTHY(100),
      1TEMP(100,2),WSEL(100),RIHYT(100),RE(100),TARA(10)
        CHARACTER*2 CRDID
        IF (ENGMET.EQ.0.) THEN
           CONV-1.98
        ELSE
           CONV-1.
        END IF
        DO 100 I-1,NSTPRS
           TEMP(I,1)-(2*SV(I)/CONV)/TMSTP
  100      TEMP(I,2)-TEMP(I,1)+OD1(I)
        CALL INTERP(NRTPTS,RE,OD1,WSEL(1),OTHY(1))
        CALL INTERP(NSTPRS,SE,TEMP(1,1),WSEL(1),DTPO)
        DTMO-DTPO-2.*OTHY(1)
        DO 110 I-2,NOTPTS
           CTM-(I-1)*TMSTP
           IF (CTM.LT.0.) CTM-0.
           PTM-(I-2)*TMSTP
           IF (PTM.LT.0.) PTM-0.
           CALL INTERP(NOTPTS,RIHYT,RIHY,CTM,CIHY)
           CALL INTERP(NOTPTS,RIHYT,RIHY,PTM,PIHY)
           RISM-CIHY+PIHY
           DTPO-RISM+DTMO
           CALL INTERP(NSTPRS,TEMP(1,2),SE,DTPO,WSEL(I))
           CALL INTERP(NRTPTS,RE,OD1,WSEL(I),OTHY(I))
```

```
            DTMO=DTPO-2.*OTHY(I)
  110   CONTINUE
        RETURN
        END
C
C Input subroutine
C
        SUBROUTINE RDIN(TARA,CRDID)
        DIMENSION TARA(10)
        CHARACTER*2 CRDID,TSTRNG*78
        DO 110 I=1,10
  110   TARA(I)=0.00
        READ (1,900) CRDID,TSTRNG
        IF (CRDID.EQ.'ZZ') THEN
            GOTO 100
        END IF
        REWIND (UNIT=3)
        WRITE (3,910) TSTRNG
        REWIND (UNIT=3)
        READ (3,*,END=100) (TARA(L),L=1,10)
  100   CONTINUE
        RETURN
  900   FORMAT (A2,A78)
  910   FORMAT (A78)
        END
C
C List Input File
C
        SUBROUTINE LISTOT
        CHARACTER*80 OUTLST
        REWIND (UNIT=1)
        DO 100 I=1,500
            READ (1,900,END=110) OUTLST
            WRITE (2,900) OUTLST
  100   CONTINUE
        WRITE (2,910)
        STOP
  110   CONTINUE
        REWIND (UNIT=1)
        DO 120 I=1,4
            READ (1,900) OUTLST
  120   CONTINUE
        WRITE (2,920)
        RETURN
  900   FORMAT (A80)
  910   FORMAT (37H*ERROR - Input File Exceeds 500 Lines)
  920   FORMAT ('1')
        END
C
C Error subroutine
C
        SUBROUTINE ERR(CRDID)
        CHARACTER*2 CRDID
```

```
      WRITE (2,900)   CRDID
      WRITE (6,900)   CRDID
      CLOSE (UNIT=1)
      CLOSE (UNIT=2)
      CLOSE (UNIT=3)
      STOP
      RETURN
 900  FORMAT (47HERROR - CARD SEQUENCE OR NUMERIC ERROR AT CARD ,A2)
      END
C
C Linear Interpolation subroutine
C
      SUBROUTINE INTERP(NPTS,X,Y,XLUP,YNEW)
      DIMENSION X(100),Y(100)
      CHARACTER*2 CRDID
      DO 100 J=2,NPTS
         IF (XLUP.EQ.X(J)) THEN
            YNEW=Y(J)
            RETURN
         END IF
         IF (XLUP.GT.X(J))GOTO 100
         MIN=J-1
         GOTO 110
 100  CONTINUE
      WRITE (2,900)
      CLOSE (UNIT=1)
      CLOSE (UNIT=2)
      CLOSE (UNIT=3)
      STOP
 110  YNEW=Y(MIN)+((XLUP-X(MIN))*((Y(MIN+1)-Y(MIN))/(X(MIN+1)-
     1X(MIN))))
      RETURN
 900  FORMAT (31HInterpolated Value Out of Range)
      END
C
C Double linear interpolation routine
C
      SUBROUTINE DBLINT(NPTS,X1,Y1,X2,Y2,DY,X,Y,VAL)
      DIMENSION X1(100),Y1(100),X2(100),Y2(100),TEMP(2)
      CHARACTER*2 CRDID
      DO 100 I=2,NPTS
         IF (X.GT.X1(I)) GOTO 100
         MIN=I-1
         GOTO 110
 100  CONTINUE
      WRITE (2,900)
      CLOSE (UNIT=1)
      CLOSE (UNIT=2)
      CLOSE (UNIT=3)
      STOP
 110  TEMP(1)=Y1(MIN)+((X-X1(MIN))*((Y1(MIN+1)-Y1(MIN))/(X1(MIN+1)-
     1X1(MIN))))
      DO 120 I=2,NPTS
```

```
            IF (X.GT.X2(I)) GOTO 120
            MIN=I-1
            GOTO 130
  120   CONTINUE
        CALL ERR(CRDID)
  130   TEMP(2)=Y2(MIN)+((X-X2(MIN))*((Y2(MIN+1)-Y2(MIN))/(X2(MIN+1)-
       1X2(MIN))))
        VAL=TEMP(1)+(Y*((TEMP(2)-TEMP(1))/DY))
        RETURN
  900   FORMAT (38HDouble Interpolated Value Out of Range)
        END
C
C Subroutine to compute SV if SA and SE are entered
C
        SUBROUTINE SVOL(SV,SE,SA,N,ENGMET)
        DIMENSION SV(100),SE(100),SA(100)
        CONV=.1
        IF (ENGMET.EQ.0) CONV=43560.
        DO 100 I=2,N
            SV(I)=(((SA(I-1)+SA(I))/2.0)*(SE(I)-
       1    SE(I-1)))/CONV
  100   CONTINUE
        RETURN
        END
C
C Outflow Subroutine
C
        SUBROUTINE OTFLW(RE,OD,CSLOPE,RMANN,NCSPRS,CE,CT,TGTUSE,
       1ENGMET,OTSTTY,TGATOD,TGTEL,TGTOPS,NRTPTS,NOOTST,NTGTOP,NTGATE,
       2VLFTOD,VLFEL,VLFOPS,VLFUSE,NVLFOP,NVLFGT,CHANEL,CHANQ)
        DIMENSION RE(100),OD(100,6),TARA(10),TEMP(100),CE(20),CT(20),
       1TGATOD(3,100,10),TGTEL(3,10),TGTOPS(3,10,2),TGTUSE(3),
       2NTGTOP(3),VLFTOD(3,100,10),VLFEL(3,10),VLFOPS(3,10,2),
       3VLFUSE(3),NVLFOP(3),CHANEL(100),CHANQ(100)
        CHARACTER*2 CRDID,CRDCK
        CHARACTER*40 OTSTTY(5)
        NTGATE=1
        NVLFGT=1
        GATWD=0.
        GTSTEL=0.
        DO 160 I=1,3
            NTGTOP(I)=0
            NVLFOP(I)=0
            VLFUSE(I)=0.
  160       TGTUSE(I)=0.
        CALL RDIN(TARA,CRDID)
        IF (CRDID.NE.'ON') CALL ERR(CRDID)
        NOOTST=TARA(1)
        BASELV=TARA(2)
        ELVMAX=TARA(3)
        NRTPTS=TARA(4)
        ELVSTP=(ELVMAX-BASELV)/NRTPTS
        NRTPTS=NRTPTS+1
```

```
      DO 120 I-1,NRTPTS
      OD(I,6)-0.0
120   RE(I)-BASELV+(I-1)*ELVSTP
      DO 100 I-1,NOOTST
         CALL RDIN(TARA,CRDID)
         IF (CRDID.EQ.'UO') THEN
            CRDCK-'UO'
            CALL UNCNOG (RE,TEMP,NCSPRS,CE,CT,ENGMET,TARA,CRDID,
1           CSLOPE,RMANN,NRTPTS,CRDCK,NTGTOP,TGTUSE,GATWD,NTGATE,
2           CRSTEL,GTSTEL,CHANEL,CHANQ,PIERNO)
            OTSTTY(I)-'Uncontrolled Ogee Spillway'
         END IF
         IF (CRDID.EQ.'UB') THEN
            CALL UNBDCR (RE,TEMP,NCSPRS,CE,CT,ENGMET,TARA,CRDID,
1           CSLOPE,RMANN,NRTPTS,CHANEL,CHANQ)
            OTSTTY(I)-'Uncontrolled Broadcrested Weir'
         END IF
         IF (CRDID.EQ.'DI') THEN
            CALL DRPINL (RE,TEMP,ENGMET,TARA,CRDID,NRTPTS)
            OTSTTY(I)-'Drop Inlet Spillway'
         END IF
         IF (CRDID.EQ.'TG') THEN
            CRDCK-'TG'
            WRITE (2,*)
            WRITE (2,930)
            WRITE (2,*)
            CALL UNCNOG (RE,TEMP,NCSPRS,CE,CT,ENGMET,TARA,CRDID,
1           CSLOPE,RMANN,NRTPTS,CRDCK,NTGTOP,TGTUSE,GATWD,NTGATE,
2           CRSTEL,GTSTEL,CHANEL,CHANQ,PIERNO)
            CALL TAINGT (RE,TEMP,NTGTOP,NRTPTS,GATWD,ENGMET,
1           TGATOD,TGTEL,CRSTEL,TGTOPS,NTGATE,PIERNO)
            OTSTTY(I)-'Tainter Gate on Spillway Crest'
            NTGATE-NTGATE+1
         END IF
         IF (CRDID.EQ.'VL') THEN
            CRDCK-'VL'
            WRITE (2,*)
            WRITE (2,940)
            WRITE (2,*)
            CALL UNCNOG (RE,TEMP,NCSPRS,CE,CT,ENGMET,TARA,CRDID,
1           CSLOPE,RMANN,NRTPTS,CRDCK,NVLFOP,VLFUSE,GATWD,NVLFGT,
2           CRSTEL,GTSTEL,CHANEL,CHANQ,PIERNO)
            CALL VLIFTG (RE,TEMP,NVLFOP,NRTPTS,GATWD,ENGMET,
1           VLFTOD,VLFEL,CRSTEL,VLFOPS,NVLFGT,GTSTEL)
            OTSTTY(I)-'Vertical Lift Gate'
            NVLFGT-NVLFGT+1
         END IF
         IF (CRDID.EQ.'OW') THEN
            CALL OTWRKS (TEMP,TARA,RE,NRTPTS,ENGMET)
            OTSTTY(I)-'Outlet Works'
         END IF
         IF (CRDID.EQ.'EL'.OR.CRDID.EQ.'DC') THEN
            OTSTTY(I)-'Input Elevation Vs Discharge'
```

```
         NLOOP=(NRTPTS/10.)+.9
         LCNT=0
230      LCNT=LCNT+1
         ICNT2=1
         DO 220 K=1,NLOOP
            IF (LCNT.NE.1) CALL RDIN(TARA,CRDID)
            IF (CRDID.EQ.'EL') THEN
               DO 200 J=ICNT2,ICNT2+9
200               RE(J)=TARA(J-ICNT2+1)
               ICNT2=ICNT2+10
            END IF
            IF (CRDID.EQ.'DC') THEN
               DO 210 J=ICNT2,ICNT2+9
                  OD(J,6)=TARA(J-ICNT2+1)
210               OD(J,I)=TARA(J-ICNT2+1)
               ICNT2=ICNT2+10
            END IF
            IF (ICNT2.EQ.1) CALL ERR(CRDID)
220      CONTINUE
         IF (LCNT.EQ.1) GOTO 230
         IF (NOOTST.GT.1) THEN
            WRITE (6,910)
            CLOSE (UNIT=3)
            CLOSE (UNIT=2)
            CLOSE (UNIT=1)
            STOP
         END IF
         NTGATE=0
         NVLFGT=0
         NRTPTS=NRTPTS-1
         RETURN
      END IF
      IF (CRDID.NE.'TG'.AND.CRDID.NE.'VL') THEN
         DO 110 J=1,NRTPTS
         OD(J,6)=OD(J,6)+TEMP(J)
110      OD(J,I)=TEMP(J)
         GOTO 100
      END IF
      IF (NTGATE.GT.4) THEN
         WRITE (2,920)
         CLOSE (UNIT=1)
         CLOSE (UNIT=2)
         CLOSE (UNIT=3)
         STOP
      END IF
      IF (NTGATE.EQ.1) THEN
         INDX1=1
      ELSE
         INDX1=NTGATE-1
      END IF
      IF (CRDID.EQ.'TG'.AND.TGTUSE(INDX1).NE.0.) THEN
         DO 130 K=1,NTGTOP(INDX1)
            IF (TGTOPS(INDX1,K,1).EQ.TGTUSE(INDX1)) GOTO 140
```

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130         CONTINUE
            WRITE (2,900)
            STOP
140         CONTINUE
            DO 150 J=1,NRTPTS
                OD(J,6)=OD(J,6)+TGATOD(INDX1,J,K)
150         OD(J,I)=TGATOD(INDX1,J,K)
         END IF
         IF (NVLFGT.GT.4) THEN
            WRITE (2,920)
            CLOSE (UNIT=1)
            CLOSE (UNIT=2)
            CLOSE (UNIT=3)
            STOP
         END IF
         IF (NVLFGT.EQ.1) THEN
            INDX1=1
         ELSE
            INDX1=NVLFGT-1
         END IF
         IF (CRDID.EQ.'VL'.AND.VLFUSE(INDX1).NE.0.) THEN
            DO 170 K=1,NVLFOP(INDX1)
                IF (VLFOPS(INDX1,K,1).EQ.VLFUSE(INDX1)) GOTO 180
170         CONTINUE
            WRITE (2,900)
            STOP
180         CONTINUE
            DO 190 J=1,NRTPTS
                OD(J,6)=OD(J,6)+VLFTOD(INDX1,J,K)
190         OD(J,I)=VLFTOD(INDX1,J,K)
         END IF
100   CONTINUE
      NVLFGT=NVLFGT-1
      NTGATE=NTGATE-1
      RETURN
900   FORMAT (43H**ERROR - Gate Opening Chosen Is NOT Listed)
910   FORMAT (43H**ERROR - ED Cards Must Be Used Alone ONLY!)
920   FORMAT (30H**ERROR - Only 3 Gate Openings)
930   FORMAT (35HTainter Gates on the Spillway Crest)
940   FORMAT (19HVertical Lift Gates)
      END
C
C Outlet Works Subroutine
C
      SUBROUTINE OTWRKS (TEMP,TARA,RE,NRTPTS,ENGMET)
      DIMENSION TEMP(100),TARA(10),RE(100),PORTPR(100,2),Q(100),
     1ELEV(100)
      DATA (PORTPR(I,1),I=1,16) /1.,1.2,1.4,1.6,1.8,2.,2.5,3.,3.5,4.,
     14.5,5.,5.5,6.,6.5,7./
      DATA (PORTPR(I,2),I=1,16) /.75,.685,.65,.62,.59,.57,.535,.505,
     1.485,.47,.465,.445,.44,.43,.435,.42/
      NPRTPR=16
      DWORMN=TARA(1)
```

```fortran
      IF (ENGMET.EQ.0.) THEN
          G=32.2
          RMNFCT=1.486
      ELSE
          G=9.81
          RMNFCT=1.
      END IF
      WRITE (2,900)
      IF (DWORMN.EQ.1.) THEN
          D=TARA(2)
          FL=TARA(3)
          RMANN=TARA(4)
          ELDTOP=TARA(5)
          ELINVT=TARA(6)
          RK=TARA(7)
      ELSE
          D=TARA(2)
          FL=TARA(3)
          E=TARA(4)
          ELDTOP=TARA(5)
          ELINVT=TARA(6)
          RK=TARA(7)
          IF (TARA(8).LE.0) THEN
              VIS=1.217E-5
          ELSE
              VIS=TARA(8)*1E-5
          END IF
      END IF
      LCNT1=1
      INIT=1
      DO 110 J=1,NRTPTS
          IF (RE(J).GE.(ELINVT+(1.01*D))) GOTO 120
          IF (RE(J).LE.ELINVT) TEMP(J)=0.
          IF (RE(J).GT.ELINVT.AND.RE(J).LT.(ELINVT+(1.01*D)))TEMP(J)=
     1    -9999999.
110   CONTINUE
120   CONTINUE
      A=.78539816*D*D
      WETPER=3.14159*D
      IF (DWORMN.EQ.1.) THEN
          SLOPE=(ELINVT+D-ELDTOP)/FL
          TQ=(RMNFCT*A*((A/WETPER)**(2./3.))*SQRT(SLOPE))/RMANN
          RKTOT=RK+(29.1*(RMANN**2.)*FL)/((A/WETPER)**(4./3.))
150       CONTINUE
          V=TQ/A
          HEAD=((V**2.)*RKTOT)/(2.*G)
          FROUNO=V/(SQRT(G*D))
          IF (FROUNO.LE.7..AND.FROUNO.GE.1.) THEN
              CALL INTERP (NPRTPR,PORTPR(1,1),PORTPR(1,2),FROUNO,YDD)
          END IF
          IF (FROUNO.LT.1.) YDD=.75
          IF (FROUNO.GT.7.) YDD=.42
          TELEV=ELDTOP-D+(D*YDD)+HEAD
```

```
        IF (INIT.EQ.1) THEN
            IF (TELEV.LE.RE(J+(LCNT1-1))) THEN
                ELEV(LCNT1)=TELEV
                Q(LCNT1)=TQ
                LCNT1=LCNT1+1
                INIT=INIT+1
                TQ=TQ*1.01
                IF (LCNT1.LT.NRTPTS-J+1) GOTO 150
            ELSE
                TQ=TQ*.99
                GOTO 150
            END IF
        ELSE
            IF (TELEV.GE.RE(J+LCNT1)) THEN
                IF (ELEV(LCNT1-1).EQ.TELEV) GOTO 160
                ELEV(LCNT1)=TELEV
                Q(LCNT1)=TQ
                LCNT1=LCNT1+1
160             CONTINUE
                TQ=TQ*1.01
                IF (LCNT1.LT.NRTPTS-J+1) GOTO 150
            ELSE
                TQ=TQ*1.01
                GOTO 150
            END IF
        END IF
    ELSE
        HGUESS=ELINVT+D-ELDTOP+.1
        TQ=A*SQRT((2.*G*HGUESS)/RK)
100     CONTINUE
        V=TQ/A
        REY=V*D/VIS
        IF (REY.GT.2100.) GOTO 3
        F=64./REY
        GOTO 1
3       EVIS=E/VIS
        ELOG=18.7*ALOG10(2.71828183)
        ED=E/D
        F=1./(1.14-2.*ALOG10(ED))**2.
        PAR=V*SQRT(F/8.)*EVIS
        IF (PAR.GT.100.) GOTO 1
        NCT=0
2       FS=SQRT(F)
        FZ=.5/(F*FS)
        ARG=ED+9.35/(REY*FS)
        FF=1./FS-1.14+2.*ALOG10(ARG)
        DF=FZ+ELOG*FZ/(ARG*REY)
        DIF=FF/DF
        F=F+DIF
        NCT=NCT+1
        IF (ABS(DIF).GT..00001.AND.NCT.LT.30) GOTO 2
1       CONTINUE
        RKTOT=RK+(F*FL/D)
```

```
            HEAD=(V**2.*RKTOT)/(2.*G)
            FROUNO=V/(SQRT(G*D))
            CALL INTERP (NPRTPR,PORTPR(1,1),PORTPR(1,2),FROUNO,YDD)
            TELEV=ELDTOP-D+(D*YDD)+HEAD
            IF (INIT.EQ.1) THEN
                IF (TELEV.LE.RE(J+(LCNT1-1))) THEN
                    ELEV(LCNT1)=TELEV
                    Q(LCNT1)=TQ
                    LCNT1=LCNT1+1
                    INIT=INIT+1
                    TQ=TQ*1.01
                    IF (LCNT1.LT.NRTPTS-J+1) GOTO 100
                ELSE
                    TQ=TQ*.99
                    GOTO 100
                END IF
            ELSE
                IF (TELEV.GE.RE(J+LCNT1)) THEN
                    IF (ELEV(LCNT1-1).EQ.TELEV) GOTO 140
                    ELEV(LCNT1)=TELEV
                    Q(LCNT1)=TQ
                    LCNT1=LCNT1+1
140                 CONTINUE
                    IF (LCNT1.LT.NRTPTS-J+1) GOTO 100
                ELSE
                    TQ=TQ*1.01
                    GOTO 100
                END IF
            END IF
        END IF
        LCNT1=LCNT1-1
        DO 130 I=J,NRTPTS
            CALL INTERP(LCNT1,ELEV,Q,RE(I),TEMP(I))
130     CONTINUE
        RETURN
900     FORMAT (12HOutlet Works)
        END
C
C Vertical Lift Gate Subroutine
C
        SUBROUTINE VLIFTG (RE,TEMP,NVLFOP,NRTPTS,GATWD,ENGMET,
     1VLFTOD,VLFEL,CRSTEL,VLFOPS,NVLFGT,GTSTEL)
        DIMENSION RE(100),TEMP(100),VLFTOD(3,100,10),VLFEL(3,10),
     1VLFOPS(3,10,2),NVLFOP(3),TARA(10)
        CHARACTER*2 CRDID
        DO 140 I=1,10
140     VLFEL(NVLFGT,I)=0.
        IF (ENGMET.EQ.0.) THEN
            G=32.2
        ELSE
            G=9.81
        END IF
        CALL RDIN(TARA,CRDID)
```

```
        IF (CRDID.NE.'VL') CALL ERR (CRDID)
        DO 100 I-1,NVLFOP(NVLFGT)
 100        VLFOPS(NVLFGT,I,1)-TARA(I)
        DO 130 J-1,NVLFOP(NVLFGT)
            GATBOT-GTSTEL+VLFOPS(NVLFGT,J,1)
            DO 120 I-1,NRTPTS
                IF (RE(I).LE.GATBOT) THEN
                    VLFTOD(NVLFGT,I,J)-TEMP(I)
                ELSE
                    IF (VLFEL(NVLFGT,J).EQ.0.) VLFEL(NVLFGT,J)-RE(I)
                    HEAD-RE(I)-CRSTEL
                    H2-RE(I)-GTSTEL
                    H1-H2-VLFOPS(NVLFGT,J,1)
                    IF (HEAD.NE.0.) THEN
                        VLFCOR-((H2**(3./2.))-(H1**(3./2.)))/(HEAD**(3./2.))
                    ELSE
                        VLFCOR-1.
                    END IF
                    IF (VLFCOR.GT.1.) VLFCOR-1.
                    VLFTOD(NVLFGT,I,J)-VLFCOR*TEMP(I)
                END IF
 120        CONTINUE
 130    CONTINUE
        RETURN
        END
C
C Tainter Gate Spillway Routine
C
        SUBROUTINE TAINGT (RE,TEMP,NTGTOP,NRTPTS,GATWD,ENGMET,
     1TGATOD,TGTEL,CRSTEL,TGTOPS,NTGATE,PIERNO)
        DIMENSION RE(100),TEMP(100),TGTOPS(3,10,2),TGATOD(3,100,10),
     1TGTEL(3,10),NTGTOP(3),TARA(10)
        CHARACTER*2 CRDID
        DO 140 I-1,10
 140    TGTEL(NTGATE,I)-0.
        IF (ENGMET.EQ.0.) THEN
            G-32.2
        ELSE
            G-9.81
        END IF
        CALL RDIN(TARA,CRDID)
        IF (CRDID.NE.'TG') CALL ERR (CRDID)
        DO 100 I-1,NTGTOP(NTGATE)
 100        TGTOPS(NTGATE,I,1)-TARA(I)
        CALL RDIN(TARA,CRDID)
        IF (CRDID.NE.'TG') CALL ERR (CRDID)
        DO 110 I-1,NTGTOP(NTGATE)
 110        TGTOPS(NTGATE,I,2)-TARA(I)
        DO 130 J-1,NTGTOP(NTGATE)
            GATBOT-CRSTEL+TGTOPS(NTGATE,J,1)
            DO 120 I-1,NRTPTS
                IF (RE(I).LE.GATBOT) THEN
                    TGATOD(NTGATE,I,J)-TEMP(I)
```

```fortran
            ELSE
            IF (TGTEL(NTGATE,J).EQ.0.) TGTEL(NTGATE,J)=RE(I)
            HEAD=RE(I)-CRSTEL
            TGATOD(NTGATE,I,J)=(TGTOPS(NTGATE,J,2)*
     1      TGTOPS(NTGATE,J,1)*GATWD*SQRT(2.*G*
     2      (HEAD-(.5*TGTOPS(NTGATE,J,1)))))*(PIERNO+1.)
            END IF
  120      CONTINUE
  130   CONTINUE
        RETURN
        END
C
C Drop Inlet Spillway
C
        SUBROUTINE DRPINL (RE,TEMP,ENGMET,TARA,CRDID,NRTPTS)
        DIMENSION RE(100),TEMP(100),TARA(10),COARA(100,4),TEMP2(100,2)
        CHARACTER*2 CRDID
        DATA (COARA(I,1),I=1,20) /.18,.2,.3,.4,.5,.6,.7,.8,.9,1.,1.1,
     1  1.2,1.3,1.4,1.5,1.6,1.7,1.8,1.9,2./
        DATA (COARA(I,2),I=1,20) /3.92,3.89,3.75,3.57,3.37,3.1,2.79,2.48,
     1  2.23,2.04,1.86,1.71,1.59,1.47,1.38,1.29,1.2,1.15,1.08,1.02/
        DATA (COARA(I,3),I=1,20) /3.99,3.98,3.86,3.7,3.5,3.24,2.91,2.6,
     1  2.34,2.12,1.94,1.79,1.65,1.54,1.44,1.34,1.26,1.19,1.12,1.09/
        DATA (COARA(I,4),I=1,20) /4.02,4.,3.87,3.72,3.54,3.32,3.02,2.68,
     1  2.4,2.2,2.01,1.86,1.7,1.59,1.48,1.39,1.3,1.23,1.17,1.11/
        NCOPT=20
        APDPTH=TARA(1)
        RADIUS=TARA(2)
        CO=TARA(3)
        CRSTEL=TARA(4)
        WRITE (2,*)
        WRITE (2,900)
        WRITE (2,*)
        DO 100 I=1,NRTPTS
           HEAD=RE(I)-CRSTEL
           IF (HEAD.LE.0) THEN
               TEMP(I)=0.
               GOTO 100
           END IF
           PDRS=APDPTH/RADIUS
           HDRS=HEAD/RADIUS
           IF (CO.LE.0.) THEN
               IF (HDRS.LT..18) THEN
                   WRITE (2,910) I
                   IF (PDRS.GT..15.AND.PDRS.LT.2.) THEN
                       DO 110 J=1,3
  110                  TEMP2(J,2)=COARA(1,J+1)
                       TEMP2(1,1)=2.0
                       TEMP2(2,1)=.3
                       TEMP2(3,1)=.15
                       NTEMP2=3
                       CALL INTERP (NTEMP2,TEMP2(1,1),TEMP2(1,2),PDRS,CO)
                   END IF
```

```fortran
                   IF (PDRS.LE..15) THEN
                       CO=4.02
                       WRITE (2,920) I
                   END IF
                   IF (PDRS.GE.2.) THEN
                       CO=3.92
                       WRITE (2,930) I
                   END IF
               END IF
               IF (HDRS.GT.2.0) THEN
                   WRITE (2,940) I
                   IF (PDRS.GT..15.AND.PDRS.LT.2.) THEN
                       DO 120 J=1,3
120                    TEMP2(J,2)=COARA(20,J+1)
                       TEMP2(1,1)=2.0
                       TEMP2(2,1)=.3
                       TEMP2(3,1)=.15
                       NTEMP2=3
                       CALL INTERP (NTEMP2,TEMP2(1,1),TEMP2(1,2),PDRS,CO)
                   END IF
                   IF (PDRS.LE..15) THEN
                       CO=1.11
                       WRITE (2,920) I
                   END IF
                   IF (PDRS.GE.2.) THEN
                       CO=1.02
                       WRITE (2,930) I
                   END IF
               END IF
               IF (PDRS.LE.2..AND.PDRS.GE..3) THEN
                   DY=2.0-.3
                   YINC=PDRS-.3
                   CALL DBLINT(NCOPT,COARA(1,1),COARA(1,2),COARA(1,1),
     1             COARA(1,3),DY,HDRS,YINC,CO)
               END IF
               IF (PDRS.LE..3.AND.PDRS.GE..15) THEN
                   DY=.3-.15
                   YINC=PDRS-.15
                   CALL DBLINT(NCOPT,COARA(1,1),COARA(1,3),COARA(1,1),
     1             COARA(1,4),DY,HDRS,YINC,CO)
               END IF
           END IF
           TEMP(I)=CO*2.*RADIUS*3.14159*(HEAD**(3./2.))
100    CONTINUE
       RETURN
900    FORMAT (19HDrop Inlet Spillway)
910    FORMAT (53H*WARNING H/Rs < .18 - .18 USED FOR COMPUTATION OF Cs#,
     1 1I3)
920    FORMAT (53H*WARNING P/Rs < .15 - .15 USED FOR COMPUTATION OF Cs#,
     1 1I3)
930    FORMAT (53H*WARNING P/Rs > 2.0 - 2.0 USED FOR COMPUTATION OF Cs#,
     1 1I3)
```

```fortran
940   FORMAT (53H*WARNING H/Rs > 2.0 - 2.0 USED FOR COMPUTATION OF Cs#,
     113)
      END
C
C Uncontrolled broadcrested weir
C
      SUBROUTINE UNBDCR (RE,TEMP,NCSPRS,CE,CT,ENGMET,TARA,CRDID,
     1CSLOPE,RMANN,NRTPTS,CHANEL,CHANQ)
      DIMENSION TEMP(100),RE(100),CE(20),CT(20),TARA(10),Q(2),
     1CHANEL(100),CHANQ(100)
      CHARACTER*2 CRDID
      WRITE (2,*)
      WRITE (2,900)
      WRITE (2,*)
      IF (TARA(1).LE.0.) THEN
         C1-3.087
      ELSE
         C1-TARA(1)
      END IF
      IF (TARA(2).LE.0.) THEN
         C2-2.45
      ELSE
         C2-TARA(2)
      END IF
      CRSTEL-TARA(3)
      CRSTWD-TARA(4)
      Z-TARA(5)
      BD-TARA(6)
      APDPTH-TARA(7)
      COESUB-TARA(8)
      NVAL-1
      DO 100 I-1,NRTPTS
         HEAD-RE(I)-CRSTEL
         IF (HEAD.LE.0) THEN
            TEMP(I)-0.
            GOTO 100
         END IF
         Q(NVAL)-C1*CRSTWD*(HEAD**(3./2.))+C2*Z*(HEAD**(5./2.))
110      CONTINUE
         IF (COESUB.LT.0.) THEN
            CALL TWATER (CSLOPE,RMANN,NCSPRS,CE,CT,Q(NVAL),TWD,
     1      CHANEL,CHANQ,ENGMET)
            RKSFLG-(TWD-CRSTEL)/HEAD
            IF (RKSFLG.LT.0.67) THEN
               RKS-1.
            ELSE
               RKS-1.0-27.8*(RKSFLG-.67)**3.
            END IF
         ELSE
            RKS-COESUB
         END IF
         CV-1.0+(.023*Q(NVAL)**2.)/((BD**2.)*(APDPTH**2.)*HEAD)
         IF (NVAL.EQ.1) NVAL-2
```

```
            Q(NVAL)-C1*CRSTWD*CV*RKS*(HEAD**(3./2.))+C2*Z*CV*RKS*(HEAD**
     1      (5./2.))
            DIFF-ABS(Q(1)-Q(2))
            IF (DIFF.GT..05) THEN
                Q(1)-Q(2)
                GOTO 110
            END IF
            TEMP(I)-Q(2)
  100   CONTINUE
        RETURN
  900   FORMAT (30HUncontrolled Broadcrested Weir)
        END
C
C Uncontrolled ogee spillway subroutine
C
        SUBROUTINE UNCNOG (RE,TEMP,NCSPRS,CE,CT,ENGMET,TARA,CRDID,
     1CSLOPE,RMANN,NRTPTS,CRDCK,NTGTOP,TGTUSE,GATWD,NTGATE,CRSTEL,
     2GTSTEL,CHANEL,CHANQ,PIERNO)
        DIMENSION RE(100),TARA(10),TEMP(100),Q(3),DC33(100,2),
     1DC67(100,2),DC133(100,2),CE(20),CT(20),CKA(100,2),TGTUSE(3),
     2EKA(100,2),RKPARA(100,5),SUBCOE(100,19),SUBCLM(100,2),NTGTOP(3),
     3CHANEL(100),CHANQ(100),SLFCHD(100),SLPFCC(100)
        CHARACTER*2 CRDID,CRDCK
        COMMON /COMBLK/ DC33,DC67,DC133,CKA,EKA,RKPARA,SUBCOE,SUBCLM
        DO 130 I-1,15
            DC33(I,1)-(I-1)*.1
            DC67(I,1)-(I-1)*.1
            DC133(I,1)-(I-1)*.1
            EKA(I,1)-(I-1)*.1
            CKA(I,1)-I+1.
            RKPARA(I,1)-.2*(I-1)
  130   CONTINUE
        DC33(15,1)-1.34
        DC67(15,1)-1.33
        DC133(15,1)-1.4
        DC33(16,1)-10.
        DC67(16,1)-10.
        DC133(16,1)-10.
        CKA(1,1)-2.15
        RKPARA(13,1)-1.325
        NDCPTS-16
        NCKAPT-10
        NEKAPT-15
        NSUBPT-14
        DO 110 I-1,41
  110   TEMP(I)-0.
        RKP-TARA(1)
        RKA-TARA(2)
        DC-TARA(3)
        APWDTH-TARA(4)
        APDPTH-TARA(5)
        CRSTHT-TARA(6)
        DESHD-TARA(7)
```

```
        PIERNO=TARA(8)
        SPLNW=TARA(9)
        PIERTY=TARA(10)
        CALL RDIN (TARA,CRDID)
        IF (CRDID.NE.CRDCK) CALL ERR(CRDID)
        CRSTEL=TARA(1)
        ADSCTM=TARA(2)
        ABTRAD=TARA(3)
        IF (TARA(4).EQ.0.) THEN
            COESUB=1.
        ELSE
            COESUB=TARA(4)
        END IF
        NSLFCC=TARA(5)
        IF (CRDCK.EQ.'TG'.OR.CRDCK.EQ.'VL') THEN
            GATWD=TARA(6)
            NTGTOP(NTGATE)=TARA(7)
            TGTUSE(NTGATE)=TARA(8)
            GTSTEL=TARA(9)
        END IF
        NLOOP=(NSLFCC/10.)+.9
        ICNT2=0
        DO 140 I=1,NLOOP
            CALL RDIN (TARA,CRDID)
            IF (CRDID.NE.CRDCK) CALL ERR(CRDID)
            DO 150 J=1,10
150             SLFCHD(J+ICNT2)=TARA(J)
            ICNT2=ICNT2+10
140     CONTINUE
        ICNT2=0
        DO 160 I=1,NLOOP
            CALL RDIN (TARA,CRDID)
            IF (CRDID.NE.CRDCK) CALL ERR(CRDID)
            DO 170 J=1,10
170             SLPFCC(J+ICNT2)=TARA(J)
            ICNT2=ICNT2+10
160     CONTINUE
        IF (ENGMET.EQ.0.) THEN
            G=32.2
        ELSE
            G=9.81
        END IF
        NQ=1
        PDHD=CRSTHT/DESHD
        IF (CRDCK.EQ.'UO') THEN
            WRITE (2,*)
            WRITE (2,900)
            WRITE (2,*)
        END IF
        IF (PDHD.LT..33) WRITE (2,910)
        IF (PDHD.GT.1.33) WRITE (2,920)
        DO 100 I=1,NRTPTS
            V=0.
```

```
        IF (RE(I).LE.CRSTEL) GOTO 100
        HEAD=RE(I)-CRSTEL
        AREA=(APDPTH+HEAD)*APWDTH
        HHDFLG=0.
        IF (RKP.LT.0.) THEN
            HDHD=HEAD/DESHD
            IF (HDHD.LT..2) THEN
                HHDFLG=1.
                IF (PIERTY.EQ.1) RKP=.047
                IF (PIERTY.EQ.2) RKP=.095
                IF (PIERTY.EQ.3) RKP=.081
                IF (PIERTY.EQ.4) RKP=.101
            END IF
            IF (HDHD.GT.1.325) THEN
                HHDFLG=2.
                IF (PIERTY.EQ.1) RKP=.000
                IF (PIERTY.EQ.2) RKP=-.009
                IF (PIERTY.EQ.3) RKP=-.014
                IF (PIERTY.EQ.4) RKP=-.031
            END IF
            IF (HDHD.GE..2.AND.HDHD.LE.1.325) THEN
                IF (PIERTY.EQ.1.) CALL INTERP (NKPPT,RKPARA(1,1),
      1         RKPARA(1,2),HDHD,RKP)
                IF (PIERTY.EQ.2.) CALL INTERP (NKPPT,RKPARA(1,1),
      1         RKPARA(1,3),HDHD,RKP)
                IF (PIERTY.EQ.3.) CALL INTERP (NKPPT,RKPARA(1,1),
      1         RKPARA(1,4),HDHD,RKP)
                IF (PIERTY.EQ.4.) CALL INTERP (NKPPT,RKPARA(1,1),
      1         RKPARA(1,5),HDHD,RKP)
            END IF
        END IF
120     CONTINUE
        HE=HEAD+((V**2.)/(2.*G))
        HEDHD=HE/DESHD
        IF (DC.LE.0) THEN
            IF (PDHD.LE..33) CALL INTERP (NDCPTS,DC33(1,1),DC33(1,2),
      1     HEDHD,DC)
            IF (PDHD.GE.1.33)CALL INTERP (NDCPTS,DC133(1,1),DC133(1,2),
      1     HEDHD,DC)
            IF (PDHD.EQ..67) CALL INTERP (NDCPTS,DC67(1,1),DC67(1,2),
      1     HEDHD,DC)
            IF (PDHD.GT..33.AND.PDHD.LT..67) THEN
                DY=.67-.33
                YINC=PDHD-.33
                CALL DBLINT(NDCPTS,DC33(1,1),DC33(1,2),DC67(1,1),
      1         DC67(1,2),DY,HEDHD,YINC,DC)
            END IF
            IF (PDHD.GT..67.AND.PDHD.LT.1.33) THEN
                DY=1.33-.67
                YINC=PDHD-.67
                CALL DBLINT(NDCPTS,DC67(1,1),DC67(1,2),DC133(1,1),
      1         DC133(1,2),DY,HEDHD,YINC,DC)
            END IF
```

```
      END IF
      HERFLG=0.
      IF (RKA.LT.0) THEN
         IF (ADSCTM.EQ.1.) THEN
            HEDR=HE/ABTRAD
            IF (HEDR.LT.2.15) THEN
               RKA=.043
               HERFLG=1.
            END IF
            IF (HEDR.GT.11.) THEN
               RKA=.10
               HERFLG=2.
            END IF
            IF (HEDR.GE.2.15.AND.HEDR.LE.11.) THEN
               CALL INTERP (NCKAPT,CKA(100,1),CKA(100,2),HEDR,RKA)
            END IF
         ELSE
            IF (HEDHD.LT.0.) RKA=0.
            IF (HEDHD.GT.1.4) RKA=.2
            IF (HEDHD.GE.0.AND.HEDHD.LE.1.4) THEN
               CALL INTERP (NEKAPT,EKA(100,1),EKA(100,1),HEDHD,RKA)
            END IF
         END IF
      END IF
      ESPLWD=SPLNW-2.*(PIERNO*RKP+RKA)*HE
      CALL INTERP (NSLFCC,SLFCHD,SLPFCC,HEAD,SLFCCF)
      Q(NQ)=DC*SLFCCF*ESPLWD*HE**(3./2.)
      HEDFLG=0.
      HDHFLG=0.
      IF (COESUB.LT.0) THEN
         CALL TWATER (CSLOPE,RMANN,NCSPRS,CE,CT,Q(NQ),TWD,CHANEL,
     1   CHANQ,ENGMET)
         IF (CHANEL(2).NE.0.) CE(1)=CHANEL(1)
         TWD=TWD-CE(1)
         Y1=(HE+CRSTEL-CE(1))/HE
         HDDHE=(HE+CRSTEL-CE(1)-TWD)/HE
         IF (HDDHE.LE.0.) THEN
            HDHFLG=1.
            PSUB=100.
         END IF
         IF (HDDHE.GT..9.AND.Y1.LT.1.07) PSUB=15.
         IF (HDDHE.GT..9.AND.Y1.GT.4.5) PSUB=0.
         IF (HDDHE.GT..9.AND.Y1.GE.1.07.AND.Y1.LE.4.5) THEN
            NTEMPT=18
            HDHFLG=2.
            CALL INTERP(NTEMPT,SUBCLM(1,1),SUBCLM(1,2),Y1,PSUB)
         END IF
         IF (HDDHE.GT.0.AND.HDDHE.LE..9) THEN
            IF (Y1.LT.1.07) THEN
               HEDFLG=1.
               CALL INTERP (NSUBPT,SUBCOE(1,1),SUBCOE(1,2),HDDHE,
     1         PSUB)
            END IF
```

```fortran
      IF (Y1.GT.4.50) THEN
         HEDFLG=2.
         CALL INTERP(NSUBPT,SUBCOE(1,1),SUBCOE(1,19),HDDHE,
     1   PSUB)
      END IF
      IF (Y1.GE.1.07.AND.Y1.LE.1.1) THEN
         DY=1.1-1.07
         YINC=Y1-1.07
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,2),
     1   SUBCOE(1,1),SUBCOE(1,3),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.1.1.AND.Y1.LE.1.15) THEN
         DY=1.15-1.1
         YINC=Y1-1.1
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,3),
     1   SUBCOE(1,1),SUBCOE(1,4),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.1.15.AND.Y1.LE.1.2) THEN
         DY=1.2-1.15
         YINC=Y1-1.15
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,4),
     1   SUBCOE(1,1),SUBCOE(1,5),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.1.2.AND.Y1.LE.1.3) THEN
         DY=1.3-1.2
         YINC=Y1-1.2
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,5),
     1   SUBCOE(1,1),SUBCOE(1,6),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.1.3.AND.Y1.LE.1.4) THEN
         DY=1.4-1.3
         YINC=Y1-1.3
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,6),
     1   SUBCOE(1,1),SUBCOE(1,7),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.1.4.AND.Y1.LE.1.5) THEN
         DY=1.5-1.4
         YINC=Y1-1.4
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,7),
     1   SUBCOE(1,1),SUBCOE(1,8),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.1.5.AND.Y1.LE.1.6) THEN
         DY=1.6-1.5
         YINC=Y1-1.5
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,8),
     1   SUBCOE(1,1),SUBCOE(1,9),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.1.6.AND.Y1.LE.1.7) THEN
         DY=1.7-1.6
         YINC=Y1-1.6
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,9),
     1   SUBCOE(1,1),SUBCOE(1,10),DY,HDDHE,YINC,PSUB)
      END IF
```

```
      IF (Y1.GE.1.7.AND.Y1.LE.1.8) THEN
         DY=1.8-1.7
         YINC=Y1-1.7
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,10),
1        SUBCOE(1,1),SUBCOE(1,11),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.1.8.AND.Y1.LE.1.9) THEN
         DY=1.9-1.8
         YINC=Y1-1.8
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,11),
1        SUBCOE(1,1),SUBCOE(1,12),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.1.9.AND.Y1.LE.2.0) THEN
         DY=2.0-1.9
         YINC=Y1-1.9
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,12),
1        SUBCOE(1,1),SUBCOE(1,13),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.2.0.AND.Y1.LE.2.25) THEN
         DY=2.25-2.
         YINC=Y1-2.
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,13),
1        SUBCOE(1,1),SUBCOE(1,14),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.2.25.AND.Y1.LE.2.5) THEN
         DY=2.5-2.25
         YINC=Y1-2.25
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,14),
1        SUBCOE(1,1),SUBCOE(1,15),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.2.5.AND.Y1.LE.3.0) THEN
         DY=3.0-2.5
         YINC=Y1-2.5
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,15),
1        SUBCOE(1,1),SUBCOE(1,16),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.3.0.AND.Y1.LE.3.5) THEN
         DY=3.5-3.0
         YINC=Y1-3.0
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,16),
1        SUBCOE(1,1),SUBCOE(1,17),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.3.5.AND.Y1.LE.4.0) THEN
         DY=4.0-3.5
         YINC=Y1-3.5
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,17),
1        SUBCOE(1,1),SUBCOE(1,18),DY,HDDHE,YINC,PSUB)
      END IF
      IF (Y1.GE.4.0.AND.Y1.LE.4.5) THEN
         DY=4.5-4.0
         YINC=Y1-4.0
         CALL DBLINT(NSUBPT,SUBCOE(1,1),SUBCOE(1,18),
1        SUBCOE(1,1),SUBCOE(1,19),DY,HDDHE,YINC,PSUB)
```

```
                  END IF
              END IF
              Q(NQ)=Q(NQ)-.01*PSUB*Q(NQ)
          ELSE
              Q(NQ)=Q(NQ)*COESUB
          END IF
          V=Q(NQ)/AREA
          IF (NQ.EQ.1) THEN
              NQ=2
              GOTO 120
          ELSE
              DIFF=ABS(Q(1)-Q(2))
              IF (DIFF.GT..01) THEN
                  Q(1)=Q(2)
                  GOTO 120
              ELSE
                  TEMP(I)=Q(2)
                  IF (HHDFLG.EQ.1.) WRITE (2,950) I
                  IF (HHDFLG.EQ.2.) WRITE (2,960) I
                  IF (HDHFLG.EQ.1.) WRITE (2,990) I
                  IF (HDHFLG.EQ.2.) WRITE (2,1000) I
                  IF (HEDFLG.EQ.1.) WRITE (2,970) I
                  IF (HEDFLG.EQ.2.) WRITE (2,980) I
                  IF (HERFLG.EQ.1.) WRITE (2,930) I
                  IF (HERFLG.EQ.2.) WRITE (2,940) I
                  NQ=1
              END IF
          END IF
  100 CONTINUE
      RETURN
  900 FORMAT (26HUncontrolled Ogee Spillway)
  910 FORMAT (51H*WARNING P/Hd < .33 - .33 USED FOR COMPUTATION OF C)
  920 FORMAT (53H*WARNING P/Hd > 1.33 - 1.33 USED FOR COMPUTATION OF C)
  930 FORMAT (54H*WARNING He/R < 2.15 - 2.15 USED FOR COMPUTATION OF Ka)
  940 FORMAT (54H*WARNING He/R > 11.0 - 11.0 USED FOR COMPUTATION OF Ka)
  950 FORMAT (51H*WARNING H/Hd < .2 - .2 USED FOR COMPUTATION OF Kp#,I3)
  960 FORMAT (53H*WARNING H/Hd > 1.3 - 1.3 USED FOR COMPUTATION OF Kp#,
     1I3)
  970 FORMAT (54H*WARNING He+D/He<1.07-1.07 USED FOR COMPUTATION OF Cs#,
     1I3)
  980 FORMAT (54H*WARNING He+D/He>4.50-4.50 USED FOR COMPUTATION OF Cs#,
     1I3)
  990 FORMAT (54H*WARNING HD/He < 0.0 - 0.0 USED FOR COMPUTATION OF Cs#,
     1I3)
 1000 FORMAT (54H*WARNING HD/He > .90 - .90 USED FOR COMPUTATION OF Cs#,
     1I3)
      END


C
C Output Subroutine
C
      SUBROUTINE OUTPUT(OTHY,NINPTS,STDY,STMN,STYR,STTM,TMINC,BLKNM,
     1WSEL,NOTPTS,TMSTP,OTSTTY,TGATOD,TGTEL,TGTOPS,OD,NRTPTS,RTFLG,
```

```
      2NOOTST,NTGTOP,ENGMET,NTGATE,TGTUSE,RE,VLFTOD,VLFEL,VLFOPS,
      3VLFUSE,NVLFOP,NVLFGT,RIHY,NSTPRS,SE,SV)
       DIMENSION OTHY(100),IDATE(100,5),WSEL(100),TGATOD(3,100,10),
      1TGTEL(3,10),TGTOPS(3,10,2),OD(100,6),TGTUSE(3),NTGTOP(3),RE(100),
      2VLFTOD(3,100,10),VLFEL(3,10),VLFOPS(3,10,2),VLFUSE(3),NVLFOP(3),
      3RIHY(100),SE(100),SV(100)
       CHARACTER*40 BLKNM,OTSTTY(5),VLFLBL,TGTLBL
       CHARACTER*6 UNIT
       VLFLBL='Vertical Lift Gate'
       TGTLBL='Tainter Gate on Spillway Crest'
       IF (ENGMET.EQ.0.) THEN
          UNIT='Feet'
       ELSE
          UNIT='Meters'
       END IF
       DO 230 J=1,NTGATE
          IF (TGTOPS(J,1,1).NE.0.) THEN
             WRITE (2,950)
             WRITE (2,*)
             WRITE (2,*)
             WRITE (2,960) J
             WRITE (2,*)
             WRITE (2,*)
             DO 100 I=1,NTGTOP(J)
                WRITE (2,970) I,TGTOPS(J,I,1),UNIT
                WRITE (2,980) TGTEL(J,I),UNIT
100          CONTINUE
             WRITE (2,*)
             WRITE (2,*)
             WRITE (2,990)
             LFSTPT=1
             LLSTPT=LFSTPT+4
             IF (NTGTOP(J).LE.5) THEN
                LLSTPT=NTGTOP(J)
             END IF
220          CONTINUE
             WRITE (2,1000) LFSTPT,LFSTPT+1,LFSTPT+2,LFSTPT+3,LFSTPT+4
             DO 210 I=1,NRTPTS
                WRITE (2,1010) RE(I),(TGATOD(J,I,K),K=LFSTPT,LLSTPT)
210          CONTINUE
             IF (NTGTOP(J).GT.5.AND.LFSTPT.LT.6) THEN
                LFSTPT=6
                LLSTPT=NTGTOP(J)
                WRITE (2,950)
                WRITE (2,960) J
                WRITE (2,*)
                GOTO 220
             END IF
          END IF
230    CONTINUE
       DO 240 J=1,NVLFGT
          IF (VLFOPS(J,1,1).NE.0.) THEN
             WRITE (2,950)
```

```
            WRITE (2,*)
            WRITE (2,*)
            WRITE (2,1020) J
            WRITE (2,*)
            WRITE (2,*)
            DO 250 I-1,NVLFOP(J)
                WRITE (2,970) I,VLFOPS(J,I,1),UNIT
                WRITE (2,980) VLFEL(J,I),UNIT
250         CONTINUE
            WRITE (2,*)
            WRITE (2,*)
            WRITE (2,990)
            LFSTPT-1
            LLSTPT-LFSTPT+4
            IF (NVLFOP(J).LE.5) THEN
                LLSTPT-NVLFOP(J)
            END IF
260         CONTINUE
            WRITE (2,1000) LFSTPT,LFSTPT+1,LFSTPT+2,LFSTPT+3,LFSTPT+4
            DO 270 I-1,NRTPTS
                WRITE (2,1010) RE(I),(VLFTOD(J,I,K),K-LFSTPT,LLSTPT)
270         CONTINUE
            IF (NVLFOP(J).GT.5.AND.LFSTPT.LT.6) THEN
                LFSTPT-6
                LLSTPT-NVLFOP(J)
                WRITE (2,950)
                WRITE (2,1020) J
                WRITE (2,*)
                GOTO 260
            END IF
        END IF
240 CONTINUE
    WRITE (2,950)
    WRITE (2,*)
    WRITE (2,1030)
    WRITE (2,*)
    LCNT3-1
    LCNT4-1
    DO 280 J-1,NOOTST
        WRITE(2,1040) J,OTSTTY(J)
        IF (OTSTTY(J).EQ.TGTLBL) THEN
            WRITE (2,1050) TGTUSE(LCNT3),UNIT
            LCNT3-LCNT3+1
        END IF
        IF (OTSTTY(J).EQ.VLFLBL) THEN
            WRITE (2,1050) VLFUSE(LCNT4),UNIT
            LCNT4-LCNT4+1
        END IF
280 CONTINUE
    WRITE (2,*)
    WRITE (2,1060)
    WRITE (2,1070) (I,I-1,5)
    WRITE (2,*)
```

D33

```
         DO 290 J=1,NRTPTS
            WRITE (2,1080) RE(J),(OD(J,K),K=1,6)
 290     CONTINUE
         IF (RTFLG.EQ.0) THEN
            WRITE (2,950)
            WRITE (2,*)
            WRITE (2,*)
            WRITE (2,910) BLKNM
            WRITE (2,*)
            WRITE (2,*)
            WRITE (2,930)
            TMSTP=TMSTP*1440.
            IDATE(1,1)=STYR
            IDATE(1,2)=STMN
            IDATE(1,3)=STDY
            IDATE(1,5)=AMOD(STTM/100,2.)*100.+.5
            IDATE(1,4)=STTM/100.
            DO 120 J=2,NOTPTS
               IDATE(J,5)=IDATE(J-1,5)+TMSTP
               DO 115 I1=1,4
 115              IDATE(J,I1)=IDATE(J-1,I1)
                  DO 130 K=1,100
                     IF(IDATE(J,5).LT.60) GOTO 140
                     IDATE(J,4)=IDATE(J,4)+1
 130                 IDATE(J,5)=IDATE(J,5)-60
 140              CONTINUE
                  DO 150 K=1,100
                     IF(IDATE(J,4).LT.24) GOTO 160
                     IDATE(J,3)=IDATE(J,3)+1
 150                 IDATE(J,4)=IDATE(J,4)-24
 160              CONTINUE
                  IDANMO=30
                  IF (IDATE(J,2).EQ.1.OR.IDATE(J,2).EQ.3.OR.IDATE(J,2).
     1            EQ.5.OR.IDATE(J,2).EQ.7.OR.IDATE(J,2).EQ.8.OR.IDATE(J,2).
     2            EQ.10.OR.IDATE(J,2).EQ.12) IDANMO=31
                  IF (IDATE(J,2).NE.2) GOTO 170
                  IDANMO=28
                  RYR=IDATE(J,1)
                  RLPYR=AMOD(ABS(RYR-1988)/4.,2.)
                  IF (RLPYR.EQ.0) IDANMO=29
 170              CONTINUE
                  IF(IDATE(J,3).LE.IDANMO) GOTO 180
                  IDATE(J,2)=IDATE(J,2)+1
                  IDATE(J,3)=IDATE(J,3)-IDANMO
                  IF (IDATE(J,2).LE.12) GOTO 190
                  IDATE(J,1)=IDATE(J,1)+1
                  IDATE(J,2)=IDATE(J,2)-12
 190              CONTINUE
                  GOTO 160
 180           CONTINUE
 120        CONTINUE
            DO 200 J=1,NOTPTS
               CALL INTERP (NSTPRS,SE,SV,WSEL(J),STORGE)
```

```
         WRITE (2,940) (IDATE(J,L),L-1,5),RIHY(J),OTHY(J),WSEL(J),
     1       STORGE
 200     CONTINUE
      END IF
      RETURN
 910  FORMAT (33HOutput Hydrograph for Reservoir: ,A40)
 920  FORMAT (F4.0)
 930  FORMAT (20H    Year  Mo Dy Hour,5X,'Inflow',5X,'Outflow',5X,
     1'Elevation',5X,'Storage')
 940  FORMAT (4X,I4,3(1X,I2),I2,4(3X,F10.1))
 950  FORMAT ('1')
 960  FORMAT (42HTainter Gate Rating Curves For Gate Number,I3)
 970  FORMAT (20HGate Opening Number ,I3,' is ',F6.2,' ',A6)
 980  FORMAT (45HFlow through this gate became orfice flow at ,
     1F10.2,' ',A6,' elevation')
 990  FORMAT (' ',30X,'Gate Opening Number')
1000  FORMAT (' ',' Elevation',5X,I3,4(9X,I3))
1010  FORMAT (' ',F10.2,5(2X,F10.2))
1020  FORMAT (48HVertical Lift Gate Rating Curves For Gate Number,I3)
1030  FORMAT (21HOutflow Rating Curves)
1040  FORMAT (' ','Outflow Structure Number',I3,' is a ',A40)
1050  FORMAT (' ',' at an opening of',F10.2,' ',A6)
1060  FORMAT (' ',29X,'Outflow Structure')
1070  FORMAT (' ',' Elevation',5X,I3,4(8X,I3),6X,' Total')
1080  FORMAT (' ',F10.2,6(1X,F10.2))
      END
C
C Internal Curve Initialization
C
      BLOCK DATA DATINT
      DIMENSION DC33(100,2),DC67(100,2),DC133(100,2),CKA(100,2),
     1EKA(100,2),RKPARA(100,5),SUBCOE(100,19),SUBCLM(100,2)
      COMMON /COMBLK/ DC33,DC67,DC133,CKA,EKA,RKPARA,SUBCOE,SUBCLM
      DATA (DC33(I,2),I-1,16) /3.1,3.195,3.29,3.385,3.475,3.565,3.65,
     13.73,3.8,3.86,3.9,3.93,3.945,3.955,3.96,3.96/
      DATA (DC67(I,2),I-1,16) /3.1,3.2,3.305,3.405,3.505,3.595,3.69,
     13.775,3.85,3.91,3.96,3.99,4.015,4.035,4.04,4.04/
      DATA (DC133(I,2),I-1,16) /3.1,3.215,3.325,3.43,3.53,3.63,3.725,
     13.82,3.9,3.97,4.025,4.065,4.105,4.125,4.14,4.14/
      DATA (CKA(I,2),I-1,10) /.043,.057,.07,.079,.086,.091,.093,.095,
     1.098,.1/
      DATA (EKA(I,2),I-1,15) /0.,.029,.052,.071,.09,.11,.123,.135,
     1.148,.161,.173,.182,.189,.192,.2/
      DATA (RKPARA(I,2),I-1,13) /.047,.038,.031,.0285,.029,.029,.025,
     1.022,.016,.01,.004,0.,0./
      DATA (RKPARA(I,3),I-1,13) /.095,.075,.0585,.044,.0325,.029,.025,
     1.021,.012,.0025,-.003,-.008,-.009/
      DATA (RKPARA(I,4),I-1,13) /.081,.063,.048,.033,.025,.018,.009,
     1.002,0.,-.007,-.012,-.014,-.014/
      DATA (RKPARA(I,5),I-1,13) /.101,.001,-.0075,-.011,-.015,-.019,
     1-.018,-.0175,-.018,-.02,-.025,-.03,-.031/
      DATA (SUBCOE(I,1),I-1,14) /0.,.05,.1,.15,.2,.25,.3,.4,.5,.6,
     1.7,.8,.85,.9/
```

```
DATA (SUBCOE(I,2),I=1,14) /100.,55.,36.5,27.5,21.,18.,16.,15.,
115.,15.,15.,15.,15.,15./
DATA (SUBCOE(I,3),I=1,14) /100.,54.,35.,25.,18.,15.5,13.5,13.,
113.,13.,13.,13.,13.,13./
DATA (SUBCOE(I,4),I=1,14) /100.,52.,33.,22.,17.,13.5,12.,10.,
110.,10.,10.,10.,10.,10./
DATA (SUBCOE(I,5),I=1,14) /100.,49.,31.,19.5,15.,12.,10.5,8.,
18.,8.,8.,8.,8.,8./
DATA (SUBCOE(I,6),I=1,14) /100.,45.,27.,17.5,13.,10.,8.,5.5,
15.5,5.5,5.5,5.5,5.5,5.5/
DATA (SUBCOE(I,7),I=1,14) /100.,42.,23.5,15.5,11.3,8.4,6.1,3.6,
13.3,3.3,3.3,3.3,3.3,3.3/
DATA (SUBCOE(I,8),I=1,14) /100.,40.,21.,14.,9.8,7.2,4.3,2.5,2.,
12.,2.,2.,2.,2./
DATA (SUBCOE(I,9),I=1,14) /100.,39.,19.,13.5,9.,6.,3.7,1.8,1.2,
11.1,1.1,1.1,1.1,1.1/
DATA (SUBCOE(I,10),I=1,14) /100.,38.,18.5,13.,8.5,5.4,3.3,1.7,
1.96,.9,.8,.7,.7,.7/
DATA (SUBCOE(I,11),I=1,14) /100.,38.,18.,12.5,8.2,5.,3.1,1.5,
1.87,.75,.5,.49,.49,.49/
DATA (SUBCOE(I,12),I=1,14) /100.,37.5,18.785,12.45,8.,4.9,3.,
11.45,.857,.525,.475,.45,.445,.445/
DATA (SUBCOE(I,13),I=1,14) /100.,39.,18.88,12.21,8.,4.914,3.02,
11.438,.842,.515,.45,.415,.41,.4/
DATA (SUBCOE(I,14),I=1,14) /100.,40.5,19.52,12.63,8.19,5.375,
13.333,1.625,.853,.562,.39,.323,.31,.3/
DATA (SUBCOE(I,15),I=1,14) /100.,43.,21.15,13.44,8.56,5.888,3.82,
11.888,.933,.6,.385,.25,.22,.2/
DATA (SUBCOE(I,16),I=1,14) /100.,53.,26.25,15.,9.41,7.,5.123,
12.717,1.62,.86,.47,.11,.03,0./
DATA (SUBCOE(I,17),I=1,14) /100.,58.,29.,17.,11.2,7.85,6.08,3.73,
12.24,1.27,.69,.2,0.,0./
DATA (SUBCOE(I,18),I=1,14) /100.,60.,31.,18.3,12.,8.5,6.66,4.19,
12.7,1.65,.93,.34,0.,0./
DATA (SUBCOE(I,19),I=1,14) /100.,60.,32.,21.,13.,9.,7.,4.5,2.9,
11.8,1.,.3,0.,0./
DATA (SUBCLM(I,1),I=1,18) /1.07,1.10,1.15,1.2,1.3,1.4,1.5,1.6,1.7,
11.8,1.9,2.,2.25,2.5,3.,3.5,4.,4.5/
DATA (SUBCLM(I,2),I=1,18) /15.,13.,10.,8.,5.5,3.3,2.,1.1,.7,.49,
1.445,.4,.3,.2,0.,0.,0.,0./
END
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MILITARY HYDROLOGY REPORTS

Report No.	No. in Series	Title	Date
TR EL-79-2	-	Proceedings of the Military Hydrology Workshop, 17-19 May 1978, Vicksburg, Mississippi	May 1979
MP EL-79-6 (Military Hydrology Series)	1	Status and Research Requirements	Dec 1979
	2	Formulation of a Long-Range Concept for Streamflow Prediction Capability	Jul 1980
	3	A Review of Army Doctrine on Military Hydrology	Jun 1981
	4	Evaluation of an Automated Water Data Base for Support to the Rapid Deployment Task Force (RDJTF)	Nov 1981
	5	A Quantitative Summary of Groundwater Yield, Depth, and Quality Data for Selected Mideast Areas (U)	Mar 1982
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	11	Identification of Ground-Water Resources in Arid Environments Using Remote Sensing Imagery	
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	14	Breach Erosion of Earthfill Dams and Flood Routing (BEED) Model	
	15	The Seismic Refraction Compression-Shear Wave Velocity Ratio as an Indicator of Shallow Water Tables: A Field Test	Nov 1987
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