Module 209

Design Hydrology (Dams)

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Module Description

Overview

This module discusses information NRCS engineers need to know to interpret and use NRCS criteria in TR-60 and Practice Standard 378. The module discusses sources of data and explains their hydrologic and hydraulic factors governing height of dams. Computer programs are identified.

Objectives

Upon completion of this module, participants will be able to

- Interpret hydrologic design criteria in TR-60 and compare with Practice Standard 378.
- Identify sources of rainfall-frequency data for applying TR-60 criteria and compare with PS 378 sources.
- explain other hydrologic and hydraulic factors governing the height of dams (Waves, TR-52).
- identify computer programs the SCS uses for hydrologic and hydraulic dam design (DAMS2).
- Perform at ASK Level 3. (perform with supervision)

Prerequisites

Modules 101-Introduction to Hydrology, 102-Precipitation, 104-Runoff Curve Number Computations, 106-Peak Discharge, 107-Hydrographs, 109-Design Hydrology, and 202-Precipitation.

Duration

Participant should take as long as necessary to complete this module. Training time for this module is approximately four hours.

Eligibility

This module is intended for all NRCS personnel who plan or design conservation practices.

Method of Completion

This module is self-paced but states should select a resource person to answer any questions that the participants' supervisor cannot handle.

Introduction

This module builds on seven other Hydrology Training Series Modules (101, 102, 104, 106, 107, 109, and 202). These modules should already have been completed. This module ties all seven of the parts together into the design of a dam. In order to complete this module, you will need access to the National Engineering Manual, Practice Standard 378, and TR-60 (refer to the appendices for most of the material).

Hydrologic Design Criteria

Background

Dam design criteria are separated by policy into two groups.

- dams less than 35 feet in height of hazard class that have a product of storage times height of less than 3000 which are covered under Practice Standard 378

- all other dams which are designed by TR-60 criteria

Dam hazard class designations are outlined in paragraph 520.20 of the National Engineering Manual.

In general, small ponds meeting Practice Standard 378 criteria have less stringent hydrologic and hydraulic requirements than those required to meet TR-60 criteria. This standard allows more frequent use of the emergency spillway to pass inflow volumes greater than the available storage volume. Practice Standard 378 criteria specifies the use of 24-hour precipitation amounts whereas TR-60 criteria includes a range of storm durations from which the most critical result is used to size the spillways.

Hydrologic Criteria

Terminology-Module 101

Introduction to Hydrology has an extensive list of definitions in its Glossary of Terms. A quick review of this glossary may be helpful.

Class of dams

Dams are classified according to the potential hazard to life and property if the dam should suddenly breach or fail. Existing and future downstream development including controls for future
development must be considered when classifying the dam. The classification of a dam is determined only by the potential hazard from failure, not by the criteria. The classes are listed below.

Class (a)-Dams in rural or agricultural areas where failure may damage farm building, agricultural land, or township and country roads.

Class (b)-Dams in predominantly rural or agricultural areas where failure may damage isolated homes, main highways, or minor railroads or interrupt service of relatively important public utilities.

Class (c)-Dams where failure may cause loss of life or serious damage to homes, industrial and commercial buildings, important public utilities, main highways, or railroads.

As stated before, Practice Standard 378 covers small dams that are of class (a) hazard less than 35 feet high and have a product of storage times the effective height which is less than 3000. Effective height is the depth in feet from the crest of the emergency spillway to the low point in the original cross section on the centerline of the dam. All other dams designed by NRCS are to be designed by criteria as stated in TR-60.

Principal Spillway Hydrograph Precipitation Amounts

Storm duration and distribution

The hydrologic criteria for sizing principal spillways is in table 2-2 of TR-60 (pg 2-7). Dams designed by Practice Standard 378 criteria may not require a principal spillway, which is recommended, but may be required by individual state regulations. The four standard 24-hour storm distributions for Practice Standard 378 dams are as shown in EFM-2 and TR-55. The storm distribution for TR-60 criteria dams is the one day-ten day event as described in chapter 21, NEH-4.
(Refer to pages 2-7 of TR-60 for Table 2-2)*

Precipitation data sources

Precipitation data for TR-60 dams requires ten-day data in addition to the 24-hour data. Ten-day precipitation data is provided by technical Paper 49 for the 37 contiguous states east of the 105th meridian; West Technical Service Center Technical Note - Hydrology - PO-6 Rev. 1973 for those states covered by NOAA Atlas 2; Technical Paper 51 for Hawaii; Technical Paper 52 for Alaska; and Technical Paper 53 for Puerto Rico and Virgin Islands. Refer to table 2-1 page 2-5 of TR-60 for a complete list of precipitation data references.
(Refer to pages 2-5 of TR-60 for Table 2-1)*

Precipitation data for practice standard 378 dams is found in Technical Paper 40 for the 37 contiguous states east of the 105th meridian; Technical Paper 42 for Puerto Rico and Virgin Islands; Technical Paper 43 for Hawaii; Technical Paper 47 for Alaska; and NOAA Atlas 2 for the eleven western states. These publications provide 24 hour precipitation amounts to be used with the four standard rainfall distributions.

Areal adjustment

The precipitation data sources listed above are for point rainfall which is considered applicable for areas up to ten square miles. For drainage areas larger than ten square miles, an areal adjustment must be made in order for the uniform precipitation amounts to apply to the entire watershed. Areal adjustment values are found in table 2-3(A) page 2-7 of TR-60. The adjustments shown are for drainage areas from ten square miles to one hundred square miles. For drainage areas greater than one hundred square miles, a special study is recommended. In addition, ten-day runoff curve number adjustments are made if the 100-year frequency ten-day point rainfall is 6.0 inches or more. table 2-3(B) of TR-60 gives the ten-day runoff curve number adjustment.
(Refer to pages 2-7 of TR-60 for Table 2-3(A and B))*

Snowmelt zone runoff

During the computations for principal spillway size, a number of volume checks must be made to assure a proper design. States falling within the snowmelt zone in the 48 contiguous states must make a check for snowmelt runoff volume as well as ten-day precipitation. The event chosen is the one that requires the higher emergency spillway crest elevation.

In the snowmelt zone of the contiguous 48 states, as shown in figures 2-l(A),(B),and (C) or Figures 2-2(A) and (B) of TR-60, a second analysis must be made using one day-ten day runoff volume. The analysis that requires the higher emergency spillway crest is used.

Quick return flow and channel losses

Corrections for Channel Losses and Quick Return Row (QRF) are dependent upon the Climatic Index (Ci) as calculated in Chapter 21 of NEH-4. Average annual precipitation and average annual temperature are used to calculate this index.

When the Ci for the drainage area above a proposed structure has a value less than 1.0, the direct runoff from the precipitation may be decreased to account for channel losses to influent streams. There is no reduction to runoff for structures during the snowmelt runoff volume analysis because those runoff volumes were developed from gage data where channel losses were a part of the data sets. Channel Loss Factors for reduction of direct runoff are available in table 21.3 page 21.6 (Rev. June 1981) in Chapter 21 of NEH-4. For drainage areas where Ci is greater than 1.0, channel losses are ignored or must be approved by the Director, Engineering Division, before being used in final design hydrology.
(Refer to page 21.6 of NEH-4 for Table 21.3)*

When the Ci is above 1.0, Quick Return Row (QRF) is added to the hydrograph or mass curve for routing. QRF is the rate of discharge that persists for some period beyond that for which the ten-day Principal Spillway Hydrograph is derived. It includes base flow and other flows that become a part of the flood hydrograph, such as

- rainfall that has infiltrated and reappeared soon afterwards as surface flow,

- drainage from marshes and potholes, and
- delayed drainage from snow banks.

QRF is added in the routings for both direct precipitation and snowmelt runoff.

Upstream releases

Releases from upstream structures must be added to the hydrograph or mass curve of runoff. This addition must be made regardless of other additions or subtractions of flow. Upstream release rates are determined from routings of applicable hydrographs or mass curves through the upstream structures and the reaches downstream from them.

The chief purpose of combining Channel Loss, Quick Return Flow, and Upstream Releases is to contribute to safe design. These methods are not intended for reproducing actual floods. If there are upstream structures, their releases are always added regardless of the downstream climatic index or other considerations.

Principal Spillway Hydrographs

Principal Spillway Hydrographs are usually developed by either TR-20 or DAMS2. TR-20 can be used for Practice Standard 378 dams since it can work with 24 hour precipitation storms compatible with their design requirements. TR-20 presently does not have the one day-ten day distribution as a stored option to develop the one day-ten day precipitation distribution for routing TR-60 type Principal Spillway design storms. DAMS2 (TR-48) is the preferred choice for development and routing of the Principal Spillway Hydrograph, and can be used for both TR-60 dams as well as Practice Standard 378 dams.

Emergency Spillway and Freeboard Hydrographs

Rows larger than those completely controllable by the principal spillway and retarding storage are safely conveyed past an earth dam by an emergency spillway. The emergency spillway is designed by use of an Emergency Spillway Hydrograph (ESH) and its minimum freeboard determined by use of a Freeboard Hydrograph (FBH). Emergency spillways are usually earth or vegetated earth spillways because of their low cost compared to structural spillways. In some situations, such as low rainfall areas or poor soil conditions, structural spillways are the only choice.

The basic concept for the use of earth or vegetated spillways is that they can be safely depended on to convey reasonable discharges for relatively short periods of time without breaching. It is to be expected that a significant discharge will damage these spillways. Such damage can be inexpensively repaired and, if the spillway does not breach during passage of the freeboard hydrograph, it will have served its basic function.

Emergency spillway precipitation criteria

Emergency spillways for Practice Standard 378 are sized to pass hydrographs developed using 24-hour amounts in accordance with table 4 on page 4 of the standard as shown below.

			Minimum design storm**	
Drainage area	Effective height of dam*	Storage	Frequency	Minimum duration
area	*ft*	*Acre-ft*	yr	*hr*
20 or less	20 or less	Less than 50	10	24
20 or less	More than 20	Less than 50	25	24
More than 20	20 or less	Less than 50	25	24
All others			50	24

*As defined under "Scope."
**Select rain distribution based on climatological region.

Table 4. Minimum spillway capacity.

Dams designed using TR-60 criteria have minimum emergency spillway hydrologic criteria as specified in table 2-5 page 2-9 in TR-60. Table 2-5 is reproduced in Appendix B.
(Refer to pages 2-9 in TR-60 for Table 2-5)*

Storm duration and distribution

The minimum storm duration to be used is six hours. If the time of concentration (Tc) exceeds six hours, the minimum design storm duration is equal to Tc. When Tc exceeds six hours, the precipitation amounts must be increased by the values in the applicable National Weather Service (NWS) references shown in figure 2-5 on page 2-17 of TR-60 (which is reproduced in Appendix B). The duration adjustment shown on graph B, figure 2-6 of TR-60 may be used in areas where NWS references are not applicable.

For those locations where National Weather Service (NWS) references provide estimates of local storm (thunderstorm) and general storm Probable Maximum Precipitation (PMP) values, the storm duration and distribution that result in the maximum reservoir stage when the hydrograph is routed through the structure should be used. Unless a specific distribution is recommended in a NWS reference, the distribution of precipitation with time should be approximately the same as that shown in graph C, figure 2-6 of TR-60. For storm durations longer than six hours, the recommended distribution from the applicable NWS reference should be used.

Precipitation areal adjustment

The precipitation amounts for the 100-year and Probable Maximum Precipitation (PMP) events are taken from the National Weather Service (NWS) references listed in table 2-1 (A) and (C) of TR-60 (which is reproduced in Appendix B). Areal adjustment and storm distribution factors contained in the NWS references are to be used in their respective regions. For areas not covered

by a NWS publication, minimum areal adjustment ratios for design precipitation amounts are shown in graph A of figure 2-6 of TR60.
(Refer to TR-60 for Table 2-1(A and C))*

Runoff volume

Runoff volume is to be determined using the runoff curve number procedure in NEH-4 using AMC II or greater. The CN applies throughout the design storm regardless of the storm duration.

Determination of ESH and FBH

Computer programs such as TR-20 and DAMS2 are used to develop Emergency Spillway Hydrographs (ESH) and Freeboard Hydrographs (FBH). TR-20 can be used for Practice Standard 378 dams using 24-hour precipitation and standard rainfall distributions. DAMS2 has a subroutine for Practice Standard 378 dams and may be the program of choice because of the specific checks incorporated in the subroutine. DAMS2 should be used for TR-60 criteria dams because it is specifically written to solve hydro graph development and routing for them. Recent changes in DAMS2 have made it possible to model extremely complex watersheds without developing the hydrographs by other methods such as TR-20 and routing the structure inflow hydrograph with DAMS2.

Emergency Spillway Capacity

Once the emergency spillway hydrograph is developed, the stage-discharge relation of a spillway is required to route the hydrograph volume through the retention volume and spillway releases.

Emergency spillway capacity for Practice Standard 378 dams may be determined by vegetal retardance. The standard allows the spillway to be sized by routing the hydrograph by starting at the crest of the principal spillway or the 10-day drawdown, whichever is higher. The standard also allows the spillway to be sized to pass the peak discharge for the required frequency of storm without routing. In this case, tables 3(A) through (E) of Chapter 11 of the Engineering Field Handbook are used to select unit discharges for determining emergency spillway width. *(Refer to Chapter 11 of the Engineering Field Handbook for Tables 3(A-E)**

Emergency spillways for dams required to meet TR-60 criteria are designed by routing the hydrograph with the starting elevation being the higher of those listed below.

- the lowest ungated principal spillway inlet
- the anticipated elevation of the sediment storage
- the elevation of the water surface associated with significant base flow
- the pool elevation after ten days of drawdown from the maximum stage attained when routing the principal spillway hydrograph.

Two exceptions are listed in TR-60 for minimum starting elevations and reference should be made to Chapter 7 of TR-60 for information and guidance.

The relationship between the water surface elevation in the reservoir and the discharge through the emergency spillway is to be evaluated by computing the head loses in the inlet channel upstream of the control section. Bernoulli's equation and Manning's formula are to be used to evaluate friction losses, compute water surface profiles and determine velocities. A Manning's "n" of 0.04 is to be used for determining the velocity and capacity in vegetated spillways. Design velocities in earth spillways will be based on an "n" value of 0.02 but the capacity of earth spillways will be based on an appraisal of the roughness condition at the site.

Dams in Series

Upper Dams in series

The hydrologic criteria and procedures for the design of an upper dam in a series of dams are the same as, or more conservative than those for dams downstream if failure of the upper dam could contribute to failure of the lower dam.

Lower dams in series

For the design of a lower dam, hydrographs are to be developed for the areas controlled by upper dams based on the same hydrologic criteria as the lower dam. The hydrographs are routed through the spillways of the upstream dams and the outflows routed to the lower dam where they are combined with the hydrograph from the intermediate uncontrolled drainage area. The combined principle spillway hydrograph is used to determine the capacity of the principal spillway and the floodwater retarding storage requirement for the lower site. The combined emergency spillway hydrograph and the combined freeboard hydrograph are used to determine the size of the emergency spillway and the height of dam at the lower site.

If the dam is overtopped or its safety is questionable upon routing a hydrograph through the upper dam, it is considered breached. For design of the lower dam, the breach hydrograph developed by TR-66 or other acceptable method is to be routed downstream to the lower dam and combined with the uncontrolled area hydrograph.

In design of the lower dam, the time of concentration (Tc) of the watershed above an upper dam is used to develop the hydrographs for the upper dam. The Tc of the uncontrolled area above the lower site is used to develop the uncontrolled area hydrographs. If the Tc for the total area exceeds six hours (calculated along the main stem), the precipitation amounts for the emergency spillway and freeboard hydrographs must be increased by the values in the applicable National Weather Service (NWS) references.

The minimum precipitation amounts for each of the required hydrographs may be reduced by the areal reduction factor for the total drainage area of the dam system.

Complex and/or large watersheds

Homogeneous sub-basins

When the area above a proposed dam exceeds 25 square miles, divide the area into hydrologically homogeneous sub-basins for developing design hydrographs. Generally, the drainage area for a sub-basin should not exceed 20 square miles. Watershed modeling computer programs, such as TR-20 or DAMS2 may be used for inflow hydrograph development. If the Tc for the entire watershed (along the main stem) exceeds six hours, storm durations longer than the Tc should be tested to determine the duration that gives the maximum reservoir stage for the routed emergency spillway and freeboard hydrographs. The storm durations usually tested include values of the watershed Tc, 12-hours, 24-hours, 48-hours, and 72-hours.

Large watersheds

For large watersheds with drainage areas more than 100-square miles, consider having the National Weather Service (NWS) make a special Probable Maximum Precipitation (PMP) study. A special study is needed because precipitation amounts may exhibit marked variation in large drainage areas. This variation is based upon topographical and meteorological parameters such as aspect, drainage orientation, mean elevation of sub-basin, and storm orientation. Individual watershed PMP studies can take into account orographic features that are smoothed in the generalized precipitation studies. A special study also may be warranted in areas where significant snow melt can occur during the design storms.

Studies to make use of available stream flow records are encouraged for purposes such as unit hydrograph development, watershed storage and timing effects, and calibration of watershed models.

Breach Studies

Some states require breach analyses to delineate flooded area before granting construction permits. The NRCS sometimes needs a breach analysis to document possible flood outlines of a breached dam to establish hazard class. The dam breach procedure described in TR-66, "simplified Dam-Breach Routing Procedures," will generally be used to determine the effects of dam failures. Other accepted methods for estimating downstream effects of dam failure, such as NWS DAMBRK, may be used.

Risk Analysis

The NRCS has not used "Risk Analysis" as a method to establish the Inflow Design Rood (IDF) but has chosen to require minimum return interval precipitation amounts to develop inflow hydrographs from which various hydraulic features are sized.

Several groups who have reviewed federal dam safety have mandated a critical review and risk assessment. The Interagency Committee on Dam Safety prepared guidelines which are part of a national effort to enhance dam safety. The developed procedure provides for routing a range of storms or trial IDF's, including a risk based analysis approach for selecting the IDF regardless of the hazards involved. A storm series is routed through the structure and downstream through the flood plain to identify damages. This storm series will include all storms less than the IDF that cause damage in the flood plain and storms up to the probable maximum flood that exceed the IDF.

Instantaneous failure is assumed when the water surface from a storm routing reaches top of dam elevation. At this point, a breach hydrograph is developed and routed downstream. For all storms equal to IDF and larger, damages will be determined for "without" failure and "with" failure conditions of the dam. In situations where the damages and inundation for the "without" failure and "with" failure are essentially the same, the point of maximum safety is known and this storm can be selected as the IDF for the dam.

Risk analysis permits the analysis of economic damages associated with flooding probabilities for various design options. All quantifiable damages are included (social, environmental, property, and crop, including replacement cost of the dam).

The role of risk assessment is to provide a formal consistent approach to evaluate the likelihood of various adverse outcomes. The probabilistic risk analysis does not replace engineering judgment and intuition, but should be used to compliment it. The purpose of a risk assessment procedure is to show tradeoffs and to give an indication of what a certain level of risk avoidance is costing.

NRCS does not plan to use a "Risk Analysis" procedure in the near future.

Activity 1, 2, and 3

At this time, complete activity one in the Study Guide to review the material just covered. After finishing the activity, compare your answers with the solution provided near the end of this module. When you are satisfied that you understand the material, you may continue with the Study Guide text.

(Refer to pages 16-19 in Module 209 for Activity 1-3 Questions and pages 30-36 for Activity 1 3 Solutions)

Identify and Compare Sources of Data for Applying TR-60 and Practice Standard 378 Criteria

NWS references

National Weather Service references for Precipitation Data used by NRCS to design dams are listed in table 2-1 of TR-60 on page 2-5. The table is subdivided into three groups as follows:
*(Refer to pages 2-5 in TR-60 for Table 2-1)**

- Durations to 1 day and return periods to 100 years
- Durations from 2 to 10 days and return periods to 100 years
- Probable Maximum Precipitation

Refer to table 2-1 to determine the proper NWS publication and obtain it from your State Hydraulic Engineer. All offices should have a copy of TP-40 and TP-49 or for those eleven western states the appropriate NOAA Atlas 2.

There may be special studies available for your area. The State Hydraulic Engineer should have copies. If the drainage area for a dam exceeds 100 square miles, a special study for PMP will be required by the National Office for that watershed to complete the dam design review.

Runoff maps

Maps for estimating minimum runoff volumes used to size principal spillways are included in TR-60. These maps (fig. 2-1 A and B) were prepared using Volume-Duration-Probability (VDP) analyses with data from available stream gage records. Northern and high elevation watersheds can have a snowmelt component in addition to rainfall. These maps were prepared to assist designers provide a safe dam design so that emergency spillways would not be required to pass flows more frequent than the return period indicated in table 2-2.
*(Refer to TR-60 for Figures 2-1 A and B)**

Other Hydraulic and Hydrologic Factors Governing the Height of Dams

TR-52

TR-52 is titled "A Guide for Design and Layout of Earth Emergency Spillways as Part of Emergency Spillway Systems for Earth Dams". This Technical Release discusses the purposes, stability, and layout of earth, vegetated earth, and structural spillways.

The TR provides guidance for design of earth emergency spillways to prevent erosion of the crest during passage of the freeboard storm event. The control parameter is the volume in ac-ft per foot of spillway bottom width. This parameter is specified in the TR as attack. Attack is compared to erosion resistance and the bulk amount of soil that must be eroded to produce breaching of the spillway. Easily eroded soils in the spillway have significantly lower allowable attack than erosion resistant soil. The TR gives some rules for layout of emergency spillways for sizing as well as physical positioning of the spillway. On easily eroded soils, the crest length becomes quite long.

A long crest length affects the hydraulics of the spillway. In general, an increase in the length of the crest and inlet channel will increase the depth of water in the pool or increase in bottom width to get an equivalent outflow through the spillway. As a result of the TR attack criteria, structures with easily eroded soils in the emergency spillway will require more overall height of the dam or wider spillway bottom width than dams with erosion resistant soils in the emergency spillway.

The TR also discusses multiple spillway systems. Primary emergency spillways in multiple emergency spillway systems are usually structural spillways or high stage inlets on the principal spillway. Secondary spillways are usually earth or vegetated earth spillways with the crest higher than the crest of the primary emergency spillway. When an engineer is designing a dam, TR-52 should be obtained and studied for guidance.

Wave height

Wave height is discussed in Technical Release 56 (TR-56). The information in TR-56 is intended for design of berm widths and vegetative cover to control embankment erosion. A procedure is explained as well as used in an example to estimate wave height in a reservoir. This methodology has broad application for developing wave height and wave energy for shore protection as well as embankment protection. If wave height is important in design, a copy of TR-56 should be obtained, studied and used to estimate the expected wave height.

In some states, the dam safety agency requires wave height be added to total dam height as an addition to emergency spillway depth at the maximum water surface during the routing of the Emergency Spillway Hydrograph or Freeboard Hydrograph. TR-56 procedures are easy to use and gives a good estimate of maximum wave height.

Diversion of Flows During Construction

During construction of dams, diversion of surface water around the site before dam completion must be considered. National Engineering Handbook Section 20 has a Construction specification 11 for Removal of Water. This specification can be used to identify the need for a diversion plan which the contractor must submit for approval before construction begins. The NRCS usually does not specify method or capacity of the diversion works, but they must be considered during design.

Selection of diversion flow discharges

To evaluate the acceptability of the contractor's submitted plan, some guidelines must be established during the design phase. TR-60 provides for increased size of principal spillway for the "...necessity to pass base and flood flows during construction." If the NRCS provides a diversion plan or scheme, the specifications must make a clear statement to the effect that the contractor is responsible to determine the adequacy of the scheme and increase the capacity if he believes the flood flows may be larger than the NRCS design provides. The contractor has the responsibility for protecting the works of improvement until the project is accepted. An extensive diversion scheme is costly to construct and maintain. The length of construction period will have an impact on necessary diversion capacity and durability. If base flow and/or seasonal high runoff periods are included in the contract period, the design capacity must provide for a higher peak discharge. If a contract extends over two or more construction seasons, then the design capacity should be something larger than a 5-yr peak discharge plus base flow. The contractor must be responsible for determining where and for how much water to design his diversion works because the risks are his to accept for the reward that may be derived from a low cost diversion plan. From a hydraulics and hydrology viewpoint, availability of data will govern the method used to estimate peak discharge for capacities.

Stream gage data available

Where stream gage data is available for analysis, a Log-Pearson Type III analysis can be made of annual peak discharges. The peak discharge for any return period can then be selected. A Volume-Duration-Probability analysis could also be made to incorporate storage in sizing of diversion works if temporary storage is available. If the site is particularly vulnerable to damage during construction, a regionalization type analysis may be made of all gage data within a 50 mile radius to develop possible peak discharge and storage requirements for diversion works.

Stream gage data unavailable

Where no stream gage data is available on the stream or no similar watersheds are available with gage data, then TR-20 analyses can be made. A series of storm frequencies can be run with various storage-outflow relationships. From this series of runs, a cost analysis can be made to make a decision on what frequency to design for, and what features are to be included. Other models may be used, but some consideration must be included in the design phase for diversion of flows.

Computer Programs

DAMS2

The DAMS2 program was first developed in 1967 to assist engineers in the hydraulic and hydrologic analyses of dams. The program develops inflow hydrographs and uses the storage-discharge relationships at dam sites to flood route the hydrographs through existing or potential reservoirs. Storage-discharge relationships may be computed by the program from physical parameters or may be directly entered into the program.

Inflow hydrographs may be accrual historical data or developed from NRCS or other design rainfall distributions. The program may be used in the design and proportioning of dams with floodwater features through the use of NRCS criteria and procedures. It also may be used to flood route historical or synthetic storms through existing dams and reservoirs.

The program can provide the hydraulic and hydrologic design for NRCS dams ranging from 20 acres in drainage area to large drainage areas where inflow hydrographs need to be developed from homogeneous subareas, combined and valley routed to the dam site. Alternate spillway sizes can be easily tested to provide satisfactory proportioning of flood storage and outflow for safety of the structure. Embankment and other construction quantities may be computed, if desired, to provide information for cost comparisons between alternates. The program will accommodate the design and analysis of dams in series

TR-20

The TR-20 computer program assists the engineer in hydrologic evaluation of flood events for use in analysis of water resource projects. The program is a single event model which computes direct runoff resulting from any synthetic or natural rainstorm. There is no provision for recovery of initial abstraction or infiltration during periods of no rainfall. It develops flood hydrographs from runoff and routes the flow through stream channels and reservoirs. It combines the routed hydrograph with those from tributaries and computes the peak discharges, their times of occurrence and the water surface elevations at any desired cross section or structure. Anyone of the above items can be printed out as well as discharge hydrograph elevations, if requested. The program provides for the analysis of up to nine different rainstorm distributions over a watershed under various combinations of land treatment, floodwater retarding structures, diversions, and channel work. Such analysis can be performed on as many as 200 reaches and 99 structures in anyone continuous run. The program uses the procedures described in the NRCS National Engineering Handbook, Section 4, Hydrology, except for the reach flood routing procedure. The reach routing procedure used is the Att-kin method.

Other programs

The Iowa Ponds (HYDROYARDAGE) program is for Class "a" dams less than 35 feet high meeting Practice Standard 378 criteria. This program was issued nationwide as one of the. programs available through the Field Office Engineering Software (FOES) Phase I program search. Many improvements have been made since its initial release. Contact the Iowa State

Engineer in Des Moines, Iowa for a User's Manual and program disk.

The FOES software will be available in the near future as a portion of FOCS. The FOCS software package is a highly integrated program with many facets. Obtain documentation from the IRM division in your state and have the program loaded for your use.

Summary

Throughout this module, an attempt has been made to explain hydraulic and hydrologic criteria as presented in TR-60 and Practice Standard 378, The difference in criteria has been cited in those conditions where they are not the same. References are listed for technical information and/or methods. Other factors which govern design have been discussed and references cited for further information and review. Computer programs that are applicable to hydrologic design of dams have been noted with some sample data shown for DAMS2.

Retain this Study Guide as a reference manual until you are satisfied that you have successfully mastered all the material covered. It will provide an easy review at any time if you should encounter a problem

If you have additional problems understanding the module or if you would like to take additional, related modules, contact your supervisor.

When you are satisfied that you have completed this module, remove the Certification of Completion sheet (last page of this Study Guide), fill it out, and give it to your supervisor to submit, though channels, to Training Officer.

Module 209 Design Hydrology (Dams) Activity Questions

Activity 1

1. Determine the hazard class of a dam with the following information.

    a. Storage at maximum water surface during routing of the principal spillway hydrograph is 387 ac-ft at elevation 2314.8.

    b. Storage at maximum water surface during routing of the Class "a" freeboard hydrograph is 541 ac-ft at elevation 2318.4.

    c. Elevation of the low point in the original cross section on centerline of the dam is 2291.1.

    d. Land use downstream of the dam is all agricultural with no buildings, roads, or major utilities to the backwaters of Hardaway Lake.

    e. County Route 21 will be incorporated into the crest of the dam.

    f. The conduit is four feet wide by five feet high.

    g. Drainage area is 1290 acres.

    h. Routing of the Class "a" freeboard hydrograph through the conduit reduces the peak flow through the conduit to 350 cfs.

2. Does this dam require an emergency spillway?

3. Can this dam be designed in accordance with Practice Standard 378?

Solution (Refer to pages 30-31 in Module 209 for Activity 1 Solutions)

Activity 2

Develop the precipitation requirements for a Practice Standard 378 Pond near Cortez, Colorado. The following site information is available.

a. Hazard class is "a".

b. Drainage area is 117 acres.

c. Storage at estimated emergency spillway crest of 6111.0 is 31. 7 ac-ft

d. Effective height of dam with crest elevation 6111.0 is 13.9 ft.

e. Land owner chooses to install a trickle tube to pass base flow and frequent events. (For this example, we will size the conduit to pass the peak of the 2-yr 24-hr hydrograph through the conduit and provide at least 1.0 feet of elevation between the principal spillway crest and the emergency spillway crest. Check your own state requirements for minimum flow, minimum conduit size, and minimum elevation criteria between principal and emergency crests.)

f. Provide a riser height adequate to allow drainage of the conservation pool for management purposes (9.0 feet).

Solution (Refer to page 32 in Module 209 for Activity 2 Solutions)

Activity 3

Prepare the precipitation data and distributions for developing the principal spillway hydrograph, the emergency spillway, and freeboard hydrographs for a Class "c" dam north of Grand Junction Colorado.

a. Drainage area = 10.5 square miles

b. Principal spillway crest elevation is 5440.0

c. Irrigation release elevation = 5403.5

d. Time of Concentration = 4.3 hours

e. Minimum conduit diameter = 30 inches (reinforced Concrete pressure Pipe)

f. Average annual precipitation = 21 inches

g. Average annual temperature = 54 degrees

Solution (Refer to pages 33-58 in Module 209 for Activity 3 Solutions)

<u>Module 209 Design Hydrology (Dams) Activity Solutions</u>

Activity 1

1. Determine the hazard class of a dam.

Solution

By reference to TR-60 page 1-1 this dam is "...located in rural or agricultural areas where failure may damage farm buildings, agricultural land or township or country roads."

Class "a"

2. Does this dam require an emergency spillway?

Solution

Refer to page 7-1 of TR-60 for criteria concerning closed type spillways.

Is the storage factor less than 10,000?

- *Storage from the routing of the PSH is 387 ac-ft*
- *Effective height = 2314.8 - 2291.1=23.7*
- *Storage factor = (23.7) (387) = 9172 < 10,000 OK*

Is the conduit area greater than 12 sq-ft? *Yes. (4) (5) = 20*

Will the inlet clog? *No. A stepped baffle riser is planned which is designed to not clog.*

Is the elbow designed to facilitate the passage of trash? *The elbow will be designed to pass any trash that will get through the trash rack.*

Will the conduit pass the routed freeboard hydrograph ? *Yes*

Is the minimum conduit capacity greater than the minimum required by Figure 7-1? *Figure 7-1 requires 340 cfs capacity at 2.02 sq-mi and the capacity of the conduit is 350 cfs.*

This dam does not require a *spillway because it meets all the required criteria. However, one end of the dam should* be *low to provide* an *overflow region.*

3. Can this dam be designed in accordance with Practice Standard 378?

Solution

Refer to Practice Standard 378 page one "Scope" for criteria.

With no emergency spillway, the top of the dam is the limit for effective height and storage.

- Effective height = 2318.4 - 2291.1 = 27.3
- Storage at 2318.4 is 541 ac-ft
- Storage factor = (27.3) (541) = 14769 > 3000

No, it cannot be designed in accordance with Practice Standard 378.

Activity 2

Develop the precipitation requirements for a Practice Standard 378 Pond near Cortez, Colorado. The following site information is available.

Solution

Refer to Table 4 of Practice Standard 378 page 378-4 for minimum design storm.

Drainage area> 20 acres

Effective height < 20 feet

Storage < 50 ac-ft

Table 4 requires 25-yr frequency and 24-hr duration storm.

- Use NOAA Atlas 2 Volume III for Colorado to select precipitation amounts.
- Select 2.5 inches from page 39
- Select 2.3 inches from page 63 (May-Oct)

Use 2.5 inches for design of emergency spillway. For 2-yr, 24-hr to size conduit,

- select 1.4 inches from page 33
- select 1.2 inches from page 57 (May-Oct)

Use 1.4 inches for design of principal spillway.

Activity 3

Prepare the precipitation data and distributions for developing the principal spillway hydrograph, the emergency spillway, and freeboard hydrographs for a Class "c" dam north of Grand Junction Colorado.

Solution

Develop one day-ten day rainfall amounts for the principal spillway hydrograph.

Refer to table 2-2 "Minimum Principal Spillway Hydrograph Criteria" to determine frequency data to use for design principal spillway conduit size. Find that for Class "c" dams, P100 is used for both earth or vegetated earth spillways.

Use NOAA Atlas 2 Volume III for Colorado to estimate 100-yr 24-hr precipitation.

- page 43 pick 2.5 inches (annual)
- page 67 pick 2.2 inches (May-Oct)

Use 2.5 inches

Develop ten-day precipitation using West Technical Service Center Note Hydrology PO-6 (Appendix B) which is applicable to the eleven western states as specified in TABLE 2-1 of TR-60. If your state is east of the 105th Meridian, select the ten-day precipitation from the proper figure in TP-49.

Estimate 2-yr, 6-hr and 24-hr precipitation amounts from NOAA Atlas 2.

- 2-yr, 6-hr pg 21 select 0.8 inches
- 2-yr, 6-hr pg 45 select 0.8 inches

Use 0.8 inches

- 2-yr, 24-hr pg 33 select 1.1 inches
- 2-yr, 24-hr pg 57 select 0.9 inches (May-Oct)

Use 1.1 inches

Select appropriate region from FIG B-1 of PO-6

Select Region 7

Estimate the 2-yr, 1-hr precipitation using the equation on page B-2 for region 7

2-yr, 1-hr=.011 + 0.942[$(0.820)^2$/1.1]=0.56

Estimate the 2-yr, 10-day precipitation amount from figure B-2 (PO-6)

Estimate 2-yr, 10 day at 1.8”

Estimate the 100-yr/2-yr 10-day precipitation ratio from figure B-3(PO-6)

Select 2.0 from map

Determine 100-yr, 10-day precipitation amount

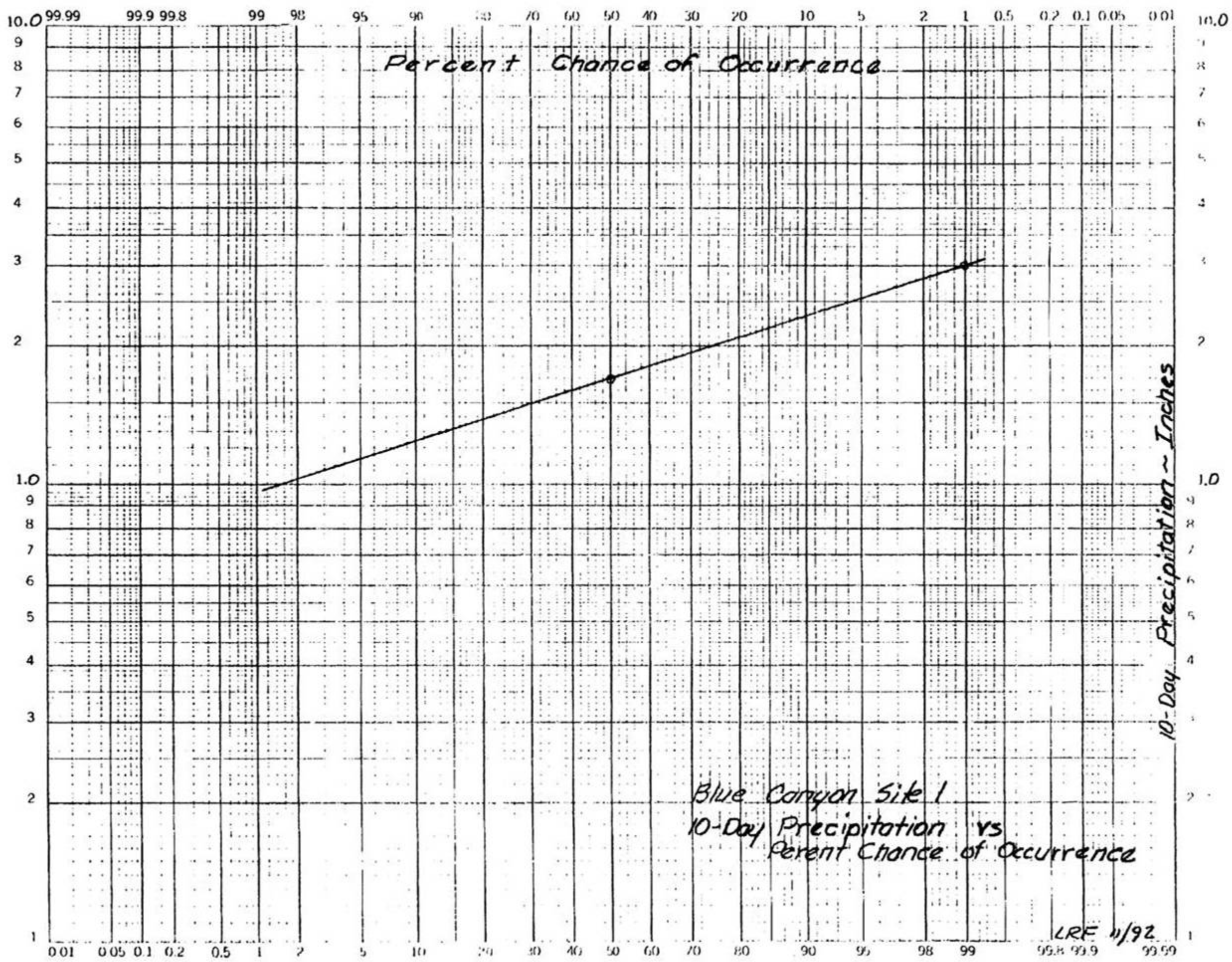
(2.0) (1.8)=3.6”

Convert partial duration series amount to annual series

(3.6) (0.88)=3.17”

Plot the 2-yr and 100-yr 10-day amounts on log-normal probability paper to obtain precipitation amounts for other return periods. See the plot on the next page. A Class “c” dam requires the 100-yr precipitation, so select P100=3.0”

At this point, the rainfall distribution could be estimated using the figure B-4(PO-6). DAMS2 has a standard rainfall distribution included for the one day-ten day analysis-use it.



Percent Chance of Occurrence
10-Day Precipitation ~ Inches
Blue Canyon Site 1
10-Day Precipitation vs
Perent Chance of Occurrence
LRF 11/92

Areal correction for point rainfall can be made by either table 2-3(A) or figure B-5(PO-6) for this watershed. The corrections from figure B-5 are:

> one-day c=0.98, prec. = (2.5) (0.98) =2.45"
>
> ten-day c=0.99, prec. = (3.0) (0.99) =2.97"
>
> If DAMS2 is used for routing, areal corrections will automatically be made if area exceeds 10.0 sq mi.

Determine Climatic Index (Ci) for estimation of channel losses and quick return flow.

> $Ci=100(Pa)/Ta^2= (100) (21)/ (54)^2=0.72$
>
> DAMS2 will automatically make the proper reduction for channel loss. Since Ci is less than 1.0, there will be no Quick Return Flow added to the Principal Spillway Hydrograph.

See the attached DAMS2 Design Input form on the following page for location of data entry for this data. (PSH Rain data)

TR-48 TYPICAL DESIGN INPUT WORKSHEET

WATERSHED	*Blue Canyon Site 1*	PREPARED BY *LFR*	DATE 11/92	SHEET	OF

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
-	-	-	-	-	-	-	-

control word	program date	title	record ID
DAMS2	02/01/89	Blue Canyon Site 1, PSH Rain, data	
STRUCTURE	Table for elevation surface area and/or volume data (discharge computed)		use form #11
CLPROFILE	Table if embankment quantities are to be computed		use form #12

	CZ	class type	RCN	DA sq. mi.	Tc hours		DRF CAM	
WSDATA*	1	C	66.	10.5	4.3			

select one for PSH	climatic index	PSH 1-DAY	PSH 10-DAY	ESH	FBH	P 10-day, 100 yr	
PDIRECT	0.72	2.5	3.2				
QDIRECT							

	unit	perm pool	PS crest	flood pool sed.	low pt. dam	
POOL DATA						

	no. conduits	conduit length	dia. or width	height	'n' conduit	tailwater elevation	
PSDATA							

	unit HS crest	Ki	weir length	HS crest	LS or if height	LS or if width	
PSINKLET							

	unit	blank to route PSH	alternate ES crests	
ESCREST				

	reference no	inlet length	'n' inlet channel	side slope ratio	'n' exit channel	exit slope	
ESDATA							

Note: Reference No. should one of the program defined profiles (#01 to 26)

	unit	alternate ES bottom widths or exit channel velocities	
BTMWITDTH			

	output options		start routing elev. (no PSH routing)
GO, DESIGN*			
ENDJOB			
ENDRUN			

*Control word descriptions may contain additional parameters that can be used.

Develop the one-day and ten-day runoff volumes for snowmelt conditions. Refer to figure 2-2(A) and (B) of TR-60.

Select 100-yr ten-day runoff of 3.0 inches from figure 2-2(A).

Select Q_1/Q_{10} ratio of volumes from figure 2-2(B) as 0.2

There is no chart for QFR because it is included in the gage data used in developing the map.

$Q_1D= (0.2)\ (3.0) =0.6''$

$Q_{10}D= 3.0''$

There are no areal corrections m ade in these amounts because the maps were derived from gage data.

On the following page, see the DAMS2 Design Input form for this data entry. (PSH runoff data)

When the Principal spillway Hydrograph routings are made, the routing with the highest water surface will control the elevation of the crest of the emergency spillway.

TR-48 TYPICAL DESIGN INPUT WORKSHEET

WATERSHED	*Blue Canyon Site 1*	PREPARED BY *LFR*	DATE 11/92	SHEET	OF

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
-	-	-	-	-	-	-	-

control word	program date	title	record ID
DAMS2	02/01/89	Blue Canyon Site 1, PSH runoff data	
STRUCTURE	Table for elevation surface area and/or volume data (discharge computed)		use form #11
CLPROFILE	Table if embankment quantities are to be computed		use form #12

	CZ	class type	RCN	DA sq. mi.	Tc hours		DRF CAM	record ID
WSDATA*	1	C	66.	10.5	4.3			

select one for PSH	climatic index	PSH 1-DAY	PSH 10-DAY	ESH	FBH	P 10-day, 100 yr	record ID
PDIRECT							
QDIRECT		0.6	3.0				

	unit	perm pool	PS crest	flood pool sed.	low pt. dam		record ID
POOL DATA							

	no. conduits	conduit length	dia. or width	height	‘n’ conduit	tailwater elevation	record ID
PSDATA							

	unit HS crest	Ki	weir length	HS crest	LS or if height	LS or if width	record ID
PSINKLET							

	unit	blank to route PSH	alternate ES crests	record ID
ESCREST				

	reference no	inlet length	‘n’ inlet channel	side slope ratio	‘n’ exit channel	exit slope	record ID
ESDATA							

Note: Reference No. should one of the program defined profiles (#01 to 26)

	unit	alternate ES bottom widths or exit channel velocities	record ID
BTMWITDTH			

	output options						start routing elev. (no PSH routing)
GO, DESIGN*							
ENDJOB							
ENDRUN							

*Control word descriptions may contain additional parameters that can be used.

Develop precipitation amounts for the Emergency Spillway and Freeboard Hydrographs.

Refer to table 2-5 of TR-60 for minimum criteria. Under Class "c" criteria, the emergency spillway precipitation requirement is PI00+0.26(PMP-PI00) and the freeboard storm is the full Probable Maximum Precipitation (PMP).

Reference to table 2-1 shows that Hydrometeorological Report 49 (HMR-49) covers the Colorado River and Great Basin drainages. (See Appendix D)

HMR-49 develops the General Storm PMP, with two components (convergence PMP and Orographic PMP), and a Local Storm PMP. The General Storm PMP is for 72 hours and the Local Storm PMP is for 6 hours. Both will be developed and the one that gives a higher water surface will be used to design the emergency spillway and height of dam. Other duration storms may be required by your state dam safety agency. The process is the same for intermediate durations. It is possible a 12 or 24 hour storm may be the most critical for your site and storm. It would be best to check at least the 12 hour event.

Compute the 72-hour General Storm PMP

Use the worksheet (table 6.1) on page 150 of HMR-49 to develop the 72-hr General Storm PMP.

See the worksheet on the following page.
(Refer to next page or page 41 in Module 209 for Table 6.1)

Table 6.1—General-storm PMP computations for the Colorado and Great Basin

Drainage *Blue Canyon Site 1* Area *10.5* mi^2

Latitude 39°11, Longitude 108°33 f basin center

Month *August*

Step		Duration (hrs) 6	12	18	24	48	72	
A. Convergence PMP								
1. Drainage average value from one of figures 2.5 to 2.16	*13.2* in (from Fig 2.12)							
2. Reduction for barrier-elevation (fig. 2.18)	*45*%							
3. Barrier-elevation reduced PMP [step 1 × step 2]	*5.9* in							
4. Durational variation [figs. 2.25 to 2.27 and table 2.7	(select 69% from fig 2.26)	*69*	*86*	*94*	*100*	*115*	*121*	%
5. Convergence PMP for indicated durations [steps 3 × 4]		*4.1*	*5.1*	*5.5*	*5.9*	*6.8*	*7.1*	in
6. Incremental 10 mi^2 (26 km^2) PMP [successive subtraction in step 5]		*4.1*	*1.0*	*0.4*	*0.4*	*0.9*	*0.3*	in
7. Areal reduction [select from figs 2.28 and 2.29]		*99*	*100*	*100*	*100*	*100*	*100*	%
8. Areally reduced PMP [step 6 ×7]		*4.1*	*1.0*	*0.4*	*0.4*	*0.9*	*0.3*	in
9. Drainage average PMP [accumulated values of step 8]		*4.1*	*5.1*	*5.5*	*5.9*	*6.8*	*7.1*	in
B. Orographic PMP								
1. Drainage average orographic index from figure 3.11a to d.	3.1 in							
2. Areal reduction [figure 3.20]	100 %							
3. Adjustment for month [one of figs. 3.12 to 3.17]	100 %							
4. Areally and seasonally adjusted PMP [steps 1 × 2 × 3]	3.1 in							
5. Durational variation [table 3.9]		*30*	*57*	*80*	*100*	*157*	*185*	%
6. Orographic PMP for given durations [steps 4 × 5]		*0.9*	*1.8*	*2.5*	*3.1*	*4.9*	*5.7*	in
C. Total PMP								
1. Add steps A9 and B6		*5.0*	*6.9*	*8.0*	*9.0*	*11.7*	*12.8*	in
2. PMP for other duration from smooth curve fitted to plot of computed data.								
3. Comparison with local-storm PMP (see sec 6.3).								

Using the completed worksheet, determine the 6-hr rainfall increments and rank them from largest to smallest. Use the values obtained in portion "C" of the worksheet. For periods 24 to 48 hours and 48 to 72 hours, eight 6-hr increments are estimated by a straight line relationship. The values for 6-, 12-, 18-, and 24-hr are used direct from the worksheet. The ranked values are shown below.

1. 5.0
2. 1.9
3. 1.1
4. 1.0
5. 0.7
6. 0.7
7. 0.7
8. 0.6
9. 0.3
10. 0.3
11. 0.3
12. 0.2

Place the 6-hr increments with the largest at 30 hours to 36 hours, the 2nd largest at 36 hours to 42 hours, and the 3rd largest at 24 hours to 30 hours etc. *(On the following pages, refer to the two Rain Table Distribution Worksheets.)*

Tabular Computations

Blue Canyon Site 1 — *LRF 11/92*

72-hour PMP General Storm

Rain Table Distribution Worksheet 4 — *1 of 2*

Group	Hour	Increment (inches)	Accumulation (total inches)	Unit Dist.	Group	Hour	Increment (inches)	Accumulation (total inches)	Unit Dist.
11th Largest	1	0.05	0.05	0.004	Largest	31	0.6	3.7	0.289
	2	0.05	0.10	0.008		32	0.6	4.3	0.336
	3	0.05	0.15	0.012		33	0.7	5.0	0.391
	4	0.05	0.20	0.016		34	0.9	5.9	0.461
	5	0.05	0.25	0.020		35	1.0	6.9	0.539
	6	0.05	0.30	0.023		36	1.2	8.1	0.633
9th Largest	7	0.05	0.35	0.027	2nd Largest	37	0.4	8.5	0.664
	8	0.05	0.40	0.031		38	0.4	8.9	0.695
	9	0.05	0.45	0.035		39	0.3	9.2	0.719
	10	0.05	0.50	0.039		40	0.3	9.5	0.742
	11	0.05	0.55	0.043		41	0.3	9.8	0.766
	12	0.05	0.60	0.047		42	0.2	10.0	0.781
7th Largest	13	0.11	0.71	0.056	4th Largest	43	0.2	10.2	0.797
	14	0.11	0.82	0.064		44	0.2	10.4	0.812
	15	0.12	0.94	0.073		45	0.2	10.6	0.828
	16	0.12	1.06	0.083		46	0.2	10.8	0.844
	17	0.12	1.18	0.092		47	0.1	10.9	0.852
	18	0.12	1.30	0.102		48	0.1	11.0	0.859
5th Largest	19	0.11	1.41	0.110	6th Largest	49	0.12	11.12	0.869
	20	0.11	1.52	0.119		50	0.12	11.24	0.878
	21	0.12	1.64	0.128		51	0.12	11.36	0.888
	22	0.12	1.76	0.138		52	0.12	11.48	0.897
	23	0.12	1.88	0.147		53	0.11	11.59	0.905
	24	0.12	2.0	0.156		54	0.11	11.70	0.914
3rd Largest	25	0.1	2.1	0.164	8th Largest	55	0.10	11.80	0.922
	26	0.2	2.3	0.180		56	0.10	11.90	0.930
	27	0.2	2.5	0.195		57	0.10	12.00	0.938
	28	0.2	2.7	0.211		58	0.10	12.10	0.945
	29	0.2	2.9	0.227		59	0.10	12.20	0.953
	30	0.2	3.1	0.242		60	0.10	12.30	0.961

Rain Table Distribution Worksheet

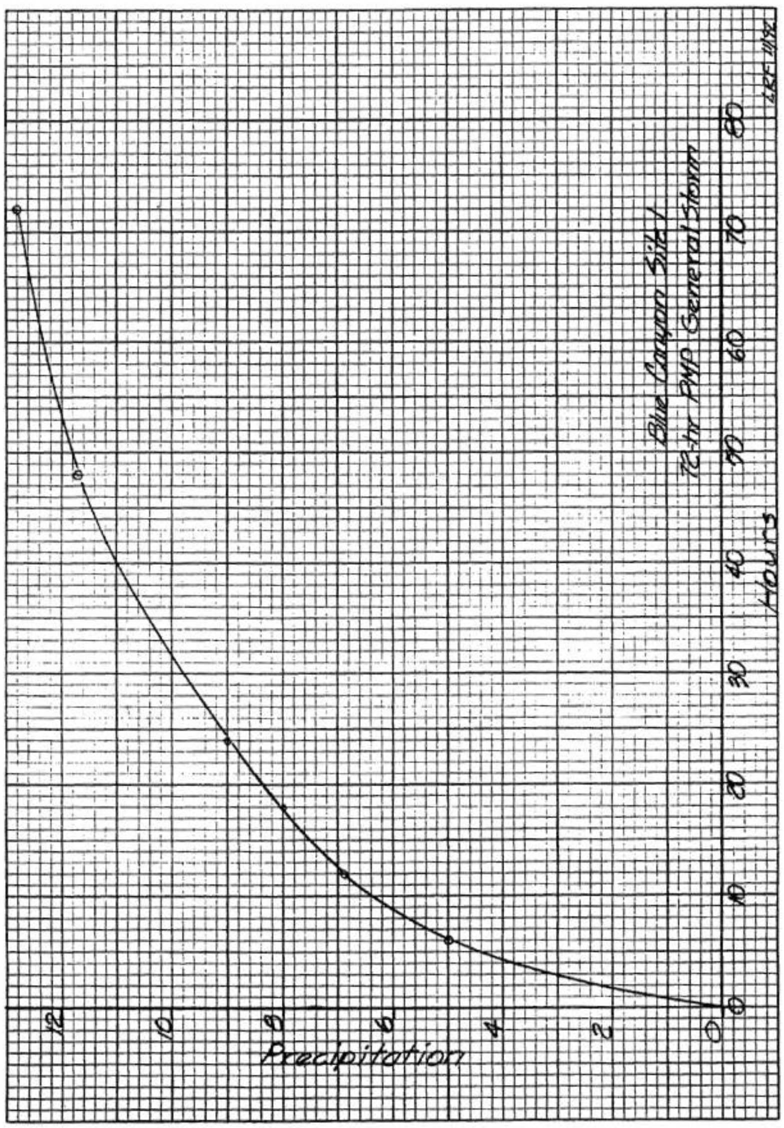
Tabular Computations	
Blue Canyon Site 1	*LRF 11/92*
72-hour PMP General Storm	
Rain Table Distribution Worksheet 4	*2 of 2*

Hour		Increment (inches)	Accumulation (total inches)	Unit Dist.		Hour	Increment (inches)	Accumulation (total inches)	Unit Dist.
10^{th} Largest	61	0.05	12.35	0.965					
	62	0.05	12.40	0.969					
	63	0.05	12.45	0.973					
	64	0.05	12.50	0.977					
	65	0.05	12.55	0.980					
	66	0.05	12.60	0.984					
12th Largest	67	0.04	12.64	0.988					
	68	0.04	12.68	0.991					
	69	0.03	12.71	0.993					
	70	0.03	12.74	0.995					
	71	0.03	12.77	0.998					
	72	0.03	12.80	1.000					

Rain Table Distribution Worksheet

Plot the Precipitation vs. Hours on arithmetic paper to help select one hour increments for the four largest 6-hr increments. *(Refer below to the graph or page 46 in Module 209.)*

6-hr Increment	1st	2nd	3rd	4th	5th	6th
1	1.2	1.0	0.9	0.7	0.6	0.6
2	0.4	0.3	0.4	0.3	0.2	0.3
3	0.2	0.2	0.2	0.2	0.2	0.1
4	0.2	0.2	0.1	0.2	0.1	0.2



Distribute remaining eight 6-hr units into one-hr increments on a straight line basis.

Distribute the one hour increments within the 6-hr unit from largest to smallest.

With the largest 6-hr unit placed at the 30 to 36 hr location, place the largest hour at 36 hours, the 2nd at 35 hours, the 3rd at 34 hours, the 4th at 33 hours, etc.

The 2nd largest 6-hr unit placed at 36 to 42 hour location, place the largest hour at 37 hours, the 2nd at 38 hours, the 3rd at 39 hours, the 4th at 40 hours, etc.

Continue distributing the hourly rainfall as shown in the Rain Table Distribution Worksheet on pages 32 and 33.

Complete the worksheet by developing the accumulated total inches column and then compute the unit distribution to make the rainfall go from 0.0 to 1.0.

When the 72-hr general storm worksheet is completed, the DAMS2 Cumulative Rainfall Table form can be filled out for inclusion into the DAMS2 run. The distribution can be entered as unit distribution as shown here or can be entered as rainfall amounts. If rainfall amounts are entered in the RAIN TABLE and a precipitation depth is entered for ESH Rainfall and FBH Rainfall on the PDIRECT card in DAMS2, the program will force the RAIN TABLE rainfall amounts into a unit distribution based on the incremental rainfall amounts in the table. I believe it is best to use unit distribution and avoid confusion.
(Refer to next page for Cumulative Rainfall Table)

TR-48 Cumulative Rainfall Table

WATERSHED	*Blue Canyon Site 1*		PREPARED BY *LFR*		DATE 11/92	SHEET	OF
1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
-	-	-	-	-	-	-	-
Control Word	Table ID	Duration hours	Label				record ID
RAINTABLE	PMPT2	72.0	72-HR General Storm PMP from HMR-49				
		Enter successive entries left to right with initial entry for time = 0					record ID
		0.000	0.004	0.008	0.012	0.016	
(maximum of 60 data records)		0.020	0.023	0.027	0.031	0.035	
		0.039	0.043	0.047	0.056	0.064	
		0.073	0.083	0.092	0.102	0.110	
		0.119	0.128	0.138	0.147	0.156	
		0.164	0.180	0.195	0.211	0.227	
		0.242	0.289	0.336	0.391	0.461	
		0.539	0.633	0.664	0.695	0.719	
		0.742	0.766	0.781	0.797	0.812	
		0.828	0.844	0.852	.0859	0.862	
		0.878	0.888	0.897	0.905	0.914	
		0.922	0.930	0.938	0.945	0.953	
		0.961	0.965	0.969	0.973	0.977	
		0.980	0.984	0.988	0.991	0.993	
		0.995	0.998	1.000			

The rainfall amounts entered on the PDIRECT card are a combination of PIOO and PMP. Refer to table 2-5 (TR-60) for the proper equation.

PESH=Pl 00+0 .26(PMP-P 100) PFBH=PMP

The 72-hr general storm duration is 72 hours in this case therefore, a 72-hr PIOO is required.

The 100-yr, ten-day precipitation amount was estimated earlier as well as the one-day amount for the principal spillway design.

Pl00, one-day=2.5"

P100, ten-day=3.2"

Use figure B-4 pg B-6 (PO-6) to plot the tw o known P100 preci pitations and estim ate Pl00, 72-hr as 2.7"
(Refer to next page or page 50 in Module 209 for figure B-4)

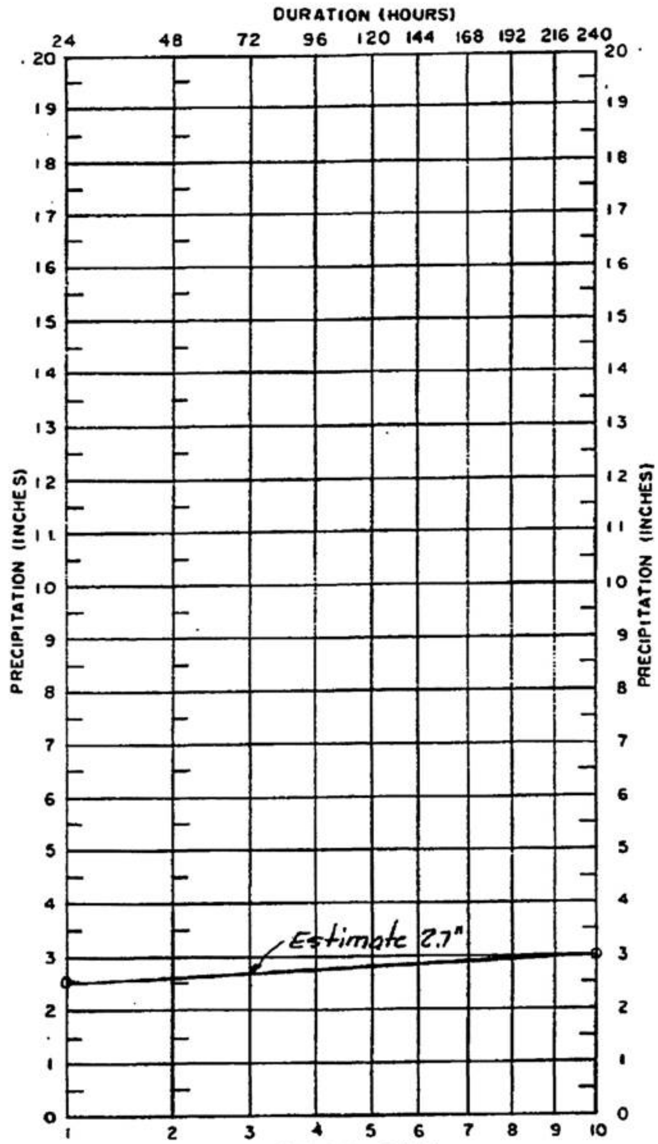


FIGURE B-4—Duration-interpolation diagram

Calculate rainfall amounts to enter on the PDIRECT card.

PESH=2.7 + 0.26(12.8-2.7)=5.33"

PFBH=PMP= 12.8"

(Refer to the following pages for the Design Input Data sheet for DAMS)

TR-48 TYPICAL DESIGN INPUT WORKSHEET

WATERSHED	*Blue Canyon Site 1*	PREPARED BY *LFR*	DATE 11/92	SHEET	OF

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
-	-	-	-	-	-	-	-

control word	program date	title	record ID
DAMS2	02/01/89	Blue Canyon Site 1, 72-HR General, storm PMP	
STRUCTURE	Table for elevation surface area and/or volume data (discharge computed)		use form #11
CLPROFILE	Table if embankment quantities are to be computed		use form #12

	CZ	class type	RCN	DA sq. mi.	Tc hours		DRF CAM	
WSDATA*	1	C	66.	10.5	4.3			

select one for PSH	climatic index	PSH 1-DAY	PSH 10-DAY	ESH	FBH	P 10-day, 100 yr	
PDIRECT	0.72	2.4	3.0	5.3	12.8	3.0	
QDIRECT							

	unit	perm pool	PS crest	flood pool sed.	low pt. dam	
POOL DATA						

	no. conduits	conduit length	dia. or width	height	'n' conduit	tailwater elevation
PSDATA						

	unit HS crest	Ki	weir length	HS crest	LS or if height	LS or if width
PSINKLET						

	unit	blank to route PSH	alternate ES crests
ESCREST			

	reference no	inlet length	'n' inlet channel	side slope ratio	'n' exit channel	exit slope
ESDATA						

Note: Reference No. should one of the program defined profiles (#01 to 26)

	unit	alternate ES bottom widths or exit channel velocities
BTMWITDTH		

	output options						start routing elev. (no PSH routing)
GO, DESIGN*		PMP T2	(optional) 72.0				
ENDJOB							
ENDRUN							

*Control word descriptions may contain additional parameters that can be used.

Compute a 6-hr Local Storm PMP

Calculate this storm for the month of August. By reference to figure 4.11 pg 128 of HMR-49 which shows regions of maximum local storm rainfall. Table 4.9 pg 127 shows the month of August with the greatest thunderstorm amounts in the state of Utah also. Use HMR-49 table 6.3A, pg 152, to calculate the 6-hr Local Storm PMP (average depth procedure).

(Refer below to figure 6.3A)

Table 6.3A—Local-storm PMP computations, Colorado River, Great Basin, and California drainages. For drainage average depth PMP. Go to table 6.3B if areal variation is required.									
Drainage *Blue Canyon Site 1*				Area *10.5* mi^2					
Latitude 39°11, Longitude 108°33				Minimum Elevation 5400 ft					
Month *August*									
Steps correspond to those in sec 6.3A.									
1. Average 1-hr 1-mi^2 (2.6-km^2) PMP for drainage [fig. 4.5]	*7.5* in								
2. a. Reduction for elevation. [No adjustment for elevations up to 5000 ft (1524 m): 5% decrease per 1000 ft (305 m) above 5000 ft (1524 m)	*98* %								
b. Multiply step 1 by step 2	*7.4* in								
3. Average 6/1-hr ratio for drainage [fig 4.7].	*1.2* in								
	Duration (hr)								
	1/4	1/2	3/4	1	2	3	4	5	6
4. Durational variation for 6/1-hr ratio of step 3 [table 4.4]	*74*	*89*	*95*	*100*	*110*	*115*	*118*	*119*	*120* %
5. 1-mi^2 (2.5 km^2) PMP for indicated durations [step 2b × step 4]	*5.5*	*6.6*	*7.0*	*7.4*	*8.1*	*8.5*	*8.7*	*8.8*	*8.9 in*
6. Areal reduction [fig. 4.9]	*74*	*78*	*81*	*82*	*84*	*85*	*86*	*87*	*88* %
7. Areally reduced PMP [step 5 × 6]	*4.1*	*5.1*	*5.7*	*6.1*	*6.8*	*7.2*	*7.5*	*7.7*	*7.8 in*
8. Incremental PMP [successive subtraction in step 7].				*6.1*	*0.7*	*0.4*	*0.3*	*0.2*	*0.1 in*
	4.1	1.0	0.6	*0.4*	{15-min. increments				
9. Time sequence of incremental PMP according to:									
Hourly increments [table 4.7]				*0.2*	*0.4*	*6.1*	*0.7*	*0.3*	*0.1 in*
Four largest 15 min. increments [table 4.8].				*0.4*	*0.6*	*1.0*	*0.1 in*		

Determine rainfall distribution for 15 minute increments as shown on worksheet for 6-hr Local Storm PMP. The unit distribution was calculated and then entered on Cumulative Rainfall Table for DAMS2.

See the 6-hr Local Storm PMP Rain Table Distribution Worksheet and the Cumulative Rainfall Table input form on the following pages. Note the placement of 15 minute increment data with the largest hour from 2 to 3 hours, the 2nd largest hour from 3 to 4 hours, the 3rd largest from 1 to 2 hours, etc.

(Refer to following pages for Rain Table Distribution Worksheet and Cumulative Rainfall Table)

Blue Canyon Site 1					LRF 11/92
72-hour PMP General Storm					
Rain Table Distribution Worksheet 4					*1 of 1*
		Time	15 min increments .	Prec. Accum	Unit Dist
5th Largest	1-hr	0.0	0.0	0.00	0.000
		0.25	0.05	0.05	0.006
		0.5	0.05	0.10	0.013
		0.75	0.05	0.15	0.019
		1.0	0.05	0.20	0.026
3th Largest	1-hr	1.25	0.1	0.30	0.033
		1.5	0.1	0.40	0.051
		1.75	0.1	0.50	0.064
		2.0	01	0.60	0.077
Largest	1-hr	2.25	0.4	1.0	0.128
		2.5	0.6	1.60	0.205
		2.75	1.0	2.60	0.333
		3.0	4.1	6.70	0.859
2nd Largest	1-hr	3.25	0.2	6.90	0.885
		3.5	0.2	7.10	0.915
		3.75	0.2	7.30	0.936
		4.0	0.1	7.40	0.949
4th Largest	1-hr	4.25	0.1	7.50	0.962
		4.5	0.1	7.60	0.974
		4.75	0.05	7.65	0.981
		5.0	0.05	7.70	0.987
6th Largest	1-hr	5.25	0.05	7.75	0.994
		5.5	0.05	7.80	1.000
		5.75	0.00	7.80	1.000
		6.0	0.00	7.80	1.000

TR-48 Cumulative Rainfall Table							
WATERSHED	*Blue Canyon Site 1*		PREPARED BY *LFR*		DATE 11/92	SHEET	OF
1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
-	-	-	-	-	-	-	-
Control Word	Table ID	Duration hours	Label				record ID
RAINTABLE	PMPT2	6.0	Local Storm PMP from HMR-49				
		Enter successive entries left to right with initial entry for time = 0					record ID
		0.000	0.006	0.013	0.019	0.026	
(maximum of 60 data records)		0.033	0.051	0.064	0.077	0.129	
		0.205	0.333	0.859	0.885	0.910	
		0.936	0.949	0.962	0.974	0.981	
		0.987	0.994	1.000	1.000	1.000	

TR-48 TYPICAL DESIGN INPUT WORKSHEET

WATERSHED	*Blue Canyon Site 1*	PREPARED BY *LFR*	DATE 11/92	SHEET	OF

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
-	-	-	-	-	-	-	-

control word	program date	title					record ID
DAMS2	02/01/89	Blue Canyon Site 1, 6-HR Local storm PMP					
STRUCTURE	Table for elevation surface area and/or volume data (discharge computed)						use form #11
CLPROFILE	Table if embankment quantities are to be computed						use form #12
	C Z / class type	RCN	DA sq. mi.	Tc hours		DRF CAM	
WSDATA*	1 / C	66.	10.5	4.3			
select one for PSH	climatic index	PSH 1-DAY	PSH 10-DAY	ESH	FBH	P 10-day, 100 yr	
PDIRECT	0.72	2.4	3.0	3.4	7.8		
QDIRECT							
	unit	perm pool	PS crest	flood pool sed.	low pt. dam		
POOL DATA							
	no. conduits	conduit length	dia. or width	height	'n' conduit	tailwater elevation	
PSDATA							
	unit HS crest	Ki	weir length	HS crest	LS or if height	LS or if width	
PSINKLET							
	unit	blank to route PSH			alternate ES crests		
ESCREST							
	reference no	inlet length	'n' inlet channel	side slope ratio	'n' exit channel	exit slope	
ESDATA							
	Note: Reference No. should one of the program defined profiles (#01 to 26)						
	unit	alternate ES bottom widths or exit channel velocities					
BTMWITDTH							
	output options						start routing elev. (no PSH routing)
GO, DESIGN*		PMP 6	(optional) 6.0				
ENDJOB							
ENDRUN							

*Control word descriptions may contain additional parameters that can be used.

The rainfall amounts to enter on the PDIRECT card in DAMS2 are developed in accordance with equations in TABLE 2-5 (TR60).

The 6-hr P100 is estimated from NOAA Atlas 2 page 31 or 55. Both give values of 1.8" (annual and May-Oct)

PESH=P100+(PMP-P100)= 1.8+0.26(7.8-1.8)=3.36"

PFBH=PMP= 7.8"

A partially completed Design Input Data form for DAMS2 is included to show where this data is entered.