ARIZONA WATER COMMISSION
DIVISION OF SAFETY OF DAMS

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GUIDELINES FOR THE DETERMINATION OF SPILLWAY CAPACITY REQUIREMENTS

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Prepared Under Direction of
Benson G. Scott, Chief
Supervision of Safety of Dams

By Joseph D. Walters

November 1974

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Revised December 1976

107.009

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INTRODUCTION

The Arizona Revised Statutes assign the responsibility for the supervision of the safety of dams to the State Water Engineer. The Statutes require that, in order to maximize protection of the public against loss of life and property by virtue of the failure of a dam, the construction, repair, enlargement, maintenance and operation of such dam must be under the approval and supervision of the State Water Engineer, acting under authority vested in the Arizona Water Commission.

One of the most important among the many factors affecting the safety of a dam is that of the adequacy of the emergency spillway. With the accelerated pace of planning and construction of proposed dams associated with flood control, recreation and water supply needs in Arizona, there has been an increase in requests to the Water Commission for guidelines and hydrologic criteria for spillway and freeboard requirements for these dams. Similarly, owners of operational dams usually want to know the basis for requests by the Water Commission to enlarge or modify the spillways on these dams. Therefore, it was deemed advisable to prepare these guidelines to assist the owner, his engineer, and other interested individuals involved in the design or modification of spillways on jurisdictional dams.

The Water Commission, through its Supervision of Safety of Dams Unit, has since 1971 generally followed the hydrologic criteria recommended by Federal agencies, notably the U.S. Soil Conservation Service. However, in 1929 the Commission's predecessor in the supervision of safety of dams, the Arizona Highway Department, promulgated rules and regulations governing the supervision, design and construction of dams entitled, "Code Governing Supervision and Control of Dams". The 1951 revised document stipulated the general requirement that, "spillways must be made large enough to accommodate the maximum probable floods without endangering the structure". This capacity requirement is still in effect today on many of the dams posing a high hazard potential. It must be recognized, however, that the science of hydrology was in its infancy prior to 1940 and the "Maximum Probable Flood" cited in the above code may be of considerably less magnitude than such a flood derived by modern hydrologic techniques. Thus, there is a need to document current criteria for establishing the hazard classification of dams and for developing hydrologic procedures and minimum capacity requirements for spillways based on the assigned hazard classification.

The following procedures and requirements will apply to all existing and proposed dams that are, or will be under the statutory jurisdiction of the State Water Engineer.

GENERAL REQUIREMENTS

The basis for assigning the hydrologic requirements for spillway capacity determination lies in the potential hazard posed by the dam. The hazard classification assigned to a dam is dependent on many factors all of which must be carefully evaluated in terms of their effects on the safety of the dam and on the magnitude of economic, environmental and human losses in the event of failure of the dam. These factors include, but are not necessarily limited to: height of dam; storage; existing and probable future downstream development; uses of reservoir; condition of dam; type of dam; size, slope, material composition and configuration of downstream stream channel; distance from dam to nearest significant downstream development; and the relative location of the spillway to the dam.

Spillways acceptable to the Water Commission must be sized in accordance with the hazard potential of the dam and may range in capacity from a size capable of safely passing the outflow from a storm with a recurrence interval of 100-years for dams of low hazard to that of the probable maximum flood for high hazard dams.

The minimum acceptable size of a spillway must have a capacity large enough to safely handle the 100-year flood outflow. However, the minimum size can rarely be justified.

HAZARD CLASSIFICATION OF DAMS

As indicated above under General Requirements, the determination of the hazard potential of a dam is dependent upon many diverse factors. The first, and perhaps the most readily categorized elements are the height of dam and the storage volume. The size categories are to be used as a guide as one of the parameters in determining the hazard potential of the dam and the basic hydrologic criteria to be used for spillway design. The larger size, as determined by either storage or height, governs the classification shown in Table 1.

As a general guide in determining the degree of potential hazard for a dam, the basic yardsticks generally used in the classification are the number of lives that could be lost and the resultant economic and environmental losses in the event of complete failure during the life of the dam. In assessing these losses, careful study must be given to all the factors which may have a bearing on the magnitude of losses. For example, it is known that an arch dam is usually prone to sudden failure in the case of severe overstress, whereas an earth dam would fail more gradually due to a failure mechanism, such as overtop.

The resultant flood wave height, instantaneous flow rate and the damage potential would be significantly greater for the arch dam failure, everything else being equal. Thus, it would appear prudent to assign a greater weight to the damage potential of the arch dam.

Environmental factors, as related to the hazard potential of a dam, are assuming increasing importance in influencing the selection of low risk criteria for the design of a proposed dam and spillway, or as an important consideration in the enlargement of an existing spillway for safety requirements. For example, in case of dam failure, storage that is proposed or is being used primarily for industrial or municipal purposes represents a greater potential economic loss and health hazard than storage used for agricultural or recreational use. Another important environmental factor, which is directly related to downstream hazard potential, is that of existing and probable future flood plain regulations associated with urban development. Effective local ordinances that restrict development within the 100-year floodplain could materially reduce the damage potential in the event of dam failure. This may be a factor to consider in assigning a hazard classification to the dam.

The existing downstream and other developments may be assessed with reasonable accuracy and can be used as one of the most important parameters in assigning the current hazard classification of a dam. However, projections of future development during the expected life of the dam are often off target and it is therefore necessary to periodically reassess the changes in development and to reclassify the hazard potential of a dam. This may mean the dam must be modified to meet higher safety requirements which is usually manifested in enlargement of the spillway.

The above are but a few of the many factors that must be considered in classifying the hazard potential of a dam. As such a classification is not conducive to a finite determination, a considerable amount of judgment must be exercised in assigning the risk and the related hydrologic criteria needed for design of a proposed dam and spillway or for the evaluation of the safe capacity requirements of an existing spillway. As a general guide, Table 2 may be used in conjunction with Table 1 in selecting the hazard potential to be assigned to a dam and as a basis for the selection of hydrologic criteria required for sizing the spillway.

REQUIRED HYDRAULIC AND HYDROLOGIC CRITERIA

An evaluation of the performance and capacity of an existing spillway, or hydraulic design studies for a spillway at a proposed dam is required to determine the ability of the structure to safely pass a flood whose magnitude is established on the basis of the hazard classification assigned to the dam. As hazard

classification is related to the risk of the structure, so is the required capacity of the spillway related to the magnitude of the spillway design flood.

Before proceeding to a discussion of hydrologic requirements, the following definitions will be helpful. The terminology is largely based on data published by Federal agencies.

100-year Flood - A flood runoff whose magnitude is expected to be equaled or exceeded, on the average, once in 100 years. Stated another way, it is a flood that has a one percent chance of being equaled or exceeded in any one year.

Probable Maximum Flood (PMF) - The flood runoff that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. The assignment of a frequency or recurrence interval to this flood is without validity and has no practical application. The magnitude of this flood is equivalent to the "Freeboard Hydrograph" for a Class "C" structure as designated by the U.S. Soil Conservation Service (see Reference No. 2, Appendix).

Probable Maximum Precipitation (PMP) - The precipitation depth which generates the PMF.

Inflow Design Flood (IDF) - The reservoir flood inflow whose magnitude has been selected for design requirements based on the assigned hazard classification of the dam. The magnitude of the IDF may range from the 100-year flood to the PMF.

Spillway Design Flood (SDF) - The routed outflow flood derived from the inflow design flood. In some cases, the inflow design flood and the spillway design flood hydrographs are essentially identical; however, the SDF hydrograph will usually have a lower peak discharge value because of attenuation of the IDF peak due to reservoir routing. This SDF peak discharge is the maximum peak discharge capacity of the spillway.

Normal Water Surface (NWS) - The storage level at which the reservoir is usually operated. This level is usually at or below the spillway crest, except in the few instances where the storage level is normally maintained above the spillway crest by means of gates or flashboards.

Maximum Storage Capacity (MSC) - The permanent storage capacity of the reservoir when the storage level is at the crest of the spillway, or at the top of permanently mounted spillway gates in closed position.

Maximum Water Surface (MWS) - The maximum elevation of the reservoir water surface attained during discharge of the spillway design flood.

Surcharge Storage - The storage volume above the spillway crest.

Total Freeboard - The vertical distance between the spillway crest and the crest of the dam.

Residual Freeboard - The vertical dimension between the maximum static water surface attained during discharge of the spillway design flood and the crest of the dam.

The inflow design flood is determined by the hydrograph of runoff selected primarily on the basis of the potential hazard assigned to the dam. As there are many factors to consider in the selection of the magnitude of this flood, it is not the purpose of these guidelines to require a specific flood frequency, volume or rainfall depth for all categories of potential hazard. However, Table 3 does provide ranges of flood magnitudes from which the inflow design flood may be selected on the basis of the designated hazard and size categories. These ranges of flood may be selected on the basis of the designated hazard and size categories. These ranges of flood magnitudes generally define the limits acceptable to the Water Commission for use as the basis for sizing the spillway.

The flood magnitudes shown in Table 3 are derived from rainfall depths for various durations and severities of storms. Both general frontal and thunderstorm type storms should be studied with due consideration given to tropical storm potential and orographic influences that may greatly increase rainfall amounts.

Recorded rainfall and flood flows in Arizona are rather sparse and the record is of short duration. Consequently, rainfall data are usually obtained from data published by the National Weather Service as listed under "References" in the Appendix.

The inflow peak flow rate usually has a greater influence than the runoff volume on the spillway capacity requirement for a dam with a small reservoir storage that is subject to storm inflow from a large watershed. In this case, the inflow design flood peak flow is essentially equal to the peak outflow rate. Conversely, a reservoir that is relatively large compared to contributing watershed will usually result in attenuation of the inflow design flood peak; in this case, the spillway peak discharge may be considerably less than the IDF peak.

RESERVOIR ROUTING REQUIREMENTS

The adequacy of the spillway for an existing dam is normally determined by routing the inflow design flood through the reservoir and spillway. The resultant outflow hydrograph is then defined as the spillway design flood hydrograph.

The design of the spillway for a proposed dam would contemplate several trial structures of differing geometric properties and crest elevations. Routings of the inflow design flood would be made through each trial structure before finally selecting the optimum spillway that meets the hydrologic capacity requirements and economic and other considerations.

Flood routings for spillway capacity determinations will normally be required to commence with the reservoir storage level at the spillway crest elevation. Infrequent exceptions would be: (1) the normal conservation storage level is below the spillway crest of a reservoir without a flood storage pool, (2) the normal upper surface of the conservation pool is limited to a level that is coincident with the bottom level of the flood control pool allocation or (3) the reservoir is used exclusively for flood control and would normally be dry. Of course, deviations from the normal starting level of routing at the spillway crest must be considered on the basis of hazard and reservoir operating procedure.

FREEBOARD REQUIREMENTS

Total freeboard is determined by the type of dam, the maximum water surface during discharge of the spillway design flood, maximum anticipated wave height and runup, and by economic factors.

Residual freeboard depends on dam type, wave height and runup and the slope and finish of the upper part of the upstream face. The minimum permissible residual freeboard for an earthfill or rockfill dam shall be the greater of either the sum of wave height and runup or three feet.

The minimum residual freeboard for a concrete dam of any type without either a parapet wall or protection against overpour shall be the same as that of an earthfill or rockfill dam.

Concrete dams provided with parapet walls exceeding the minimum residual freeboard height, or concrete dams provided with adequate splash impact protection at the toe, need no other residual freeboard requirements except that which the owner may wish to provide.

TABLE 1

SIZE CLASSIFICATION OF DAM

Size Designation	Height of Dam (feet)*	Reservoir Storage Volume (acre feet)**
Small	6 to 25	15 to 200
Medium	26 to 75	201 to 10,000
Large	over 75	over 10,000

*Measured from the lowest elevation of the outside limit of the dam to the spillway crest, or to the top of the gates when permanent gates are mounted on the spillway crest for the purpose of storing water above the spillway crest.

**Measured to the spillway crest, or to the top of permanently mounted spillway gates.

TABLE 2

POTENTIAL HAZARD CLASSIFICATION OF DAMS

Potential Hazard Class	Probable Losses	
	Probable Loss of Life	Economic & Environmental Loss
Low	None- No human habitation	Loss minor - Light damage to isolated agriculture buildings, farm lands, unimproved roads.
Moderate	Appreciable - Several habitable dwellings	Loss significant - Moderate damage to dwellings, farm buildings, improved roads, light industrial complexes. Temporary interruption of water and sewage services.
High	Moderate to severe -	Loss extreme - Severe damage or complete loss of homes, major highways, railroads, industrial plants and utilities. Major interruption of water and sewage services, resulting in severe health hazard.

TABLE 3

SPILLWAY CAPACITY REQUIREMENTS

Classification of Dams		
Potential Hazard Category	Size Designation	Inflow Design Flood Magnitude
Low	Small	100-year
	Medium	100-year to ½ PMF
	Large	½ PMF
Moderate	Small	100-year to ½ PMF
	Medium	½ PMF
	Large	½ PMF to PMF
High	Small	½ PMF
	Medium	PMF
	Large	PMF

R E F E R E N C E S

1. Arizona Revised Statutes, Title 45, Chapter 3, Article I.

2. SCS National Engineering Handbook, Section 4, Hydrology, August 1972.

3. Design of Small Dams, 2nd Edition, U.S. Department of Interior, Bureau of Reclamation, 1973.

4. "Manual of Engineering Practice, No. 28," Hydrology Handbook, American Society of Civil Engineers, Revised Edition.

5. Paper No. 38, "General Estimates of Probable Maximum Precipitation for the United States West of the 105th Meridian for Areas to 400 Square Miles and Durations to 24 Hours." National Oceanic and Atmospheric Administration. National Weather Service, Technical Papers, Washington D.C., 1969.