ARIZONA DEPARTMENT OF WATER RESOURCES
OFFICE OF DAM SAFETY AND FLOOD MITIGATION
Dam Safety Section

FLOOD PROTECTION FOR DAMS WITH NO SPILLWAYS
General Guidelines

Revised April 1996

The Arizona Department of Water Resources (ADWR), Dam Safety Section has regulatory authority for the safe construction, maintenance and operation of jurisdictional dams to safeguard life and property. In this context it is always desirable to have jurisdictional dams constructed with a spillway in order to safely pass the design flood without encroaching on the established standard for freeboard. Dams without spillways are considered less safe and are undesirable except under special conditions.

ADWR may consider approval of the construction of a jurisdictional dam without a spillway for one of the following special conditions:

1. The dam completely encloses the reservoir so that only direct precipitation enters the reservoir; or

2. The dam and reservoir are constructed either for the direct or related containment of pollutants as defined in A.R.S. 49-201.24, and the runoff from contributing drainages is zero to relatively small.

The construction of a jurisdictional dam without a spillway shall also be contingent upon ADWR approval of the two following conditions:

1. The reservoir is operated in compliance with an approved Reservoir Rule Curve using reliable and adequate drawdown facilities to transfer excess reservoir storage to alternate storage facilities. The Reservoir Rule Curve establishes the maximum allowable operating level for the reservoir and is based upon maintaining the minimum flood pool storage and dam freeboard required for each period of the year; and

2. The operating life of the dam is defined as relatively brief, generally on the order of 30 years or less, and at the end of the defined life closure of the dam is assured to remove the dam from jurisdiction.

ADWR suggests that the design engineers and dam owners contact ADWR staff early in the planning and design phases to discuss the proposed dam design. This communication will clarify early in the project whether ADWR concurs that special conditions exist for the proposed project which warrant construction of a dam without a spillway.

ADWR recognizes that this guideline may not be directly applicable to all projects and that other special conditions may exist where construction of a dam with no spillway appears appropriate. For

these cases, as well as where approaches to analyzing the flood protection may differ from this guideline, ADWR should be contacted as soon as possible for concurrence.
The license for dams without spillways will be issued for the defined operating life of the dam, or the continuous, active operating period, whichever is the shorter period of time. Approval of a request to extend the license beyond the originally defined life of the dam would be considered by ADWR providing a detailed review of the existing dam by ADWR confirmed the apparent safety of the dam. The owner shall provide acceptable evidence of financial capability, when required, to assure that the dam will be safely closed and removed from jurisdiction at the end of the defined operating life.

This guideline provides the minimum level of design criteria in relation to the hazard potential which is determined based upon the estimated consequences of the hypothetical failure of the dam. The guideline requires a stringent level of flood protection for the safety of high and significant hazard potential dams which may be approved for constructed without spillways. The guideline for low hazard potential dams with no spillway requires only minimal flood pool storage, based on the assumption that failure would only impact the owner as a result of the loss of an operating dam.

In all instances the owner and design engineer are responsible for the selection of the final design criteria, providing the criteria meet or exceed the minimums provided in this guideline. The owner or design engineer may choose to select final design criteria which exceed the minimums provided in this guideline, depending upon the direct impacts on the owner from a hypothetical failure of the dam. The owner or design engineer may choose to select design criteria which exceed the guideline for low hazard potential dams if, for example, failure of the dam would have a significant adverse impact on the continued operations of the overall facility.

This guideline for the minimum flood protection required by ADWR for dams with no spillway is general in order to provide flexibility in design to meet both the owner's operational requirements, and the dam safety requirements of ADWR. The guideline must be judiciously applied by the owner/designer to the specific conditions of the proposed dam in order to safely construct and operate dams in Arizona.

I. Flood Protection for High and Significant Hazard Potential Dams Constructed With No Spillways

The four items presented below constitute the minimum flood protection required by ADWR for high and significant hazard potential dams constructed with no spillway. The appendix describes an acceptible technical approach to determining the minimum required dam crest elevation and an approved Reservoir Rule Curve to be used during operation of the reservoir.

1. The antecedent storage level in the reservoir may be selected by the dam owner or design engineer, as required for facility operations.

    A. The planning process to select the antecedent storage level in the reservoir shall satisfy the requirement by ADWR to draw down the reservoir any time the pool level rises above the Reservoir Rule Curve into the designated flood storage.

    B. The antecedent storage level in the reservoir will typically be based upon the specific maximum reservoir volume required for operation of the facility plus containment of

runoff from a wet season sequence or storm event selected by the owner/designer, or perhaps required by another regulatory agency. The larger the antecedent condition the less likely the reservoir will have to be drawn down during the operational life.

C. The storm event or series of events selected to determine the runoff portion of the antecedent storage should be based upon a rational consideration of available historical precipitation and/or stream gage data. The data used should be as site- specific as possible. The runoff portion of the antecedent storage should generally be based upon site-specific historical wet season data and sequences except when a lack of data requires another approach. Use of a specific storm event or some other method of analysis may alternatively be appropriate. The proposed method of determining the runoff portion of the antecedent storage shall be discussed with ADWR early in the planning phases of the facility design to have concurrence on the final methodology.

D. An average of the annual maximum reservoir volume developed from water balance analyses for both dry and wet years cycles should not be used to select the maximum annual antecedent reservoir storage. This value would not be typical of a wet year period and is counter to the objective of containing runoff during higher precipitation years.

2. The reservoir flood pool shall be sized to contain the maximum runoff volume from the Probable Maximum Flood (PMF). The maximum reservoir level shall include the flood pool storage plus the design antecedent pool storage (operational storage plus design year water balance). The design criteria for flood storage will usually be the 72-Hour PMF storm event. However, several other PMF storm durations shall be analyzed to confirm the results of the climatological-hydrological analyses. Snow pack and other seasonal impacts on runoff conditions shall be included in the analyses, when geographically appropriate.

   Diversion facilities such as channels and/or secondary dams which are designed to control the PMF runoff may be used to route runoff from all, or only selected, adjacent drainage areas past the reservoir. Provision for control of sediment and debris or reduced efficiency of diversion structures from sediment and debris shall be included in the design. Diversion facilities which are designed to contain runoff from events smaller than the PMF Storm event may be advantageous for the daily operations of the facility and may be included in the design. However, failure of these lessor designed diversion facilities shall be assumed as soon as routed runoff exceeds the peak capacity of the structure during the PMF Storm event, and the entire PMF Storm event runoff from all upstream areas shall be included as inflow to the reservoir. Diversion facilities must also have all permits which may be required by regulatory agencies.

3. A minimum residual freeboard shall be provided for the dam crest above the maximum reservoir level. The minimum freeboard shall be either the sum of the wave height plus wave runup or three (3) feet, whichever is the greater vertical distance. The maximum reservoir level plus the required freeboard establishes the minimum dam crest elevation.

4. A reliable drawdown system must be provided and operated to maintain the reservoir level at or below the approved Reservoir Rule Curve, as required for flood pool storage and freeboard. This drawdown system shall be capable of evacuating, at a minimum, the runoff from the 100-Year Storm event within 10 days or less. The 100-Year Storm Event should be

preceded within 5 days by a 25-Year Event, at a minimum, to pre-wet the drainage and provide realistic runoff volumes for the larger event.

A. The owner/designer must evaluate and design a reliable drawdown system based upon an integrated system which includes the reservoir, direct precipitation runoff, runoff from adjacent drainage areas, and the presence and effectiveness of diversion facilities.

B. The alternate storage area designated to hold fluids transferred from the reservoir during the drawdown periods must also have all permits required by appropriate regulatory agencies. If the alternate structure is a jurisdictional dam it must also be designed and constructed to the same ADWR standards as the primary storage facility.

II. Flood Protection for Low Hazard Potential Dams Constructed With No Spillways

The four items presented below constitute the minimum flood protection required by ADWR for low hazard potential dams constructed with no spillway.

1. The antecedent storage level in the reservoir may be selected by the dam owner or design engineer, as required for facility operations.

   A. The planning process to select the antecedent storage level in the reservoir shall satisfy the requirement by ADWR to draw down the reservoir any time the pool level rises above the approved Maximum Allowable Reservoir Level into the designated flood storage.

   B. The antecedent storage level in the reservoir will typically be based upon the specific maximum reservoir volume required for operation of the facility plus containment of runoff from a wet season sequence or storm event selected by the owner/designer, or perhaps required by another regulatory agency. The larger the antecedent condition the less likely the reservoir will have to be drawn down during the operational life.

   C. The storm event or series of events selected to determine the runoff portion of the antecedent storage should be based upon a rational consideration of available historical precipitation and/or stream gage data. The data used should be as site- specific as possible. The runoff portion of the antecedent storage should generally be based upon site-specific historical wet season data and sequences except when a lack of data requires another approach. Use of a specific storm event or some other method of analysis may alternatively be appropriate. The proposed method of determining the runoff portion of the antecedent storage shall be discussed with ADWR early in the planning phases of the facility design to have concurrence on the final methodology.

   D. An average of the annual maximum reservoir volume developed from water balance analyses for both dry and wet years cycles should not be used to select the maximum annual antecedent reservoir storage. This value would not be typical of a wet year period and is counter to the objective of containing runoff during higher precipitation years.

2. The reservoir flood pool shall be sized, at a minimum, to contain the maximum runoff from

the 100-Year Storm event. The maximum reservoir level shall include the flood pool storage plus the design antecedent pool storage (operational storage plus design year water balance). The 100-Year Storm Event should be preceded within 5 days by a 25-Year Event, at a minimum, to pre-wet the drainage and provide realistic runoff volumes for the larger event. Snow pack and other seasonal impacts on runoff conditions must be included in the analyses, when geographically appropriate.

Diversion facilities such as channels and/or secondary dams which are designed to control the 100-Year Storm event runoff may be used to route runoff from all, or only selected, adjacent drainage areas past the reservoir. Provision for control of sediment and debris or reduced efficiency of diversion structures from sediment and debris shall be included in the design. Diversion facilities which are designed to contain runoff from events smaller than the 100-Year Storm event may be advantageous for the daily operations of the facility and may be included in the design. However, failure of these lessor designed diversion facilities shall be assumed as soon as routed runoff exceeds the peak capacity of the structure during the 100-Year Storm event, and the entire 100-Year Storm runoff from all upstream areas shall be included as inflow to the reservoir. Diversion facilities must also have all permits which may be required by regulatory agencies.

3. A minimum residual freeboard shall be provided for the dam crest above the maximum reservoir level. The minimum freeboard shall be either the sum of the wave height plus wave runup or three (3) feet, whichever is the greater vertical distance. The maximum reservoir level plus the required freeboard establishes the minimum dam crest elevation.

4. A reliable drawdown system shall be provided and operated to maintain the reservoir level at or below the approved Maximum Allowable Reservoir Level as required for flood pool storage and dam freeboard. The drawdown system shall be capable of evacuating, at a minimum, the runoff from the 100-Year Storm event within 10 days or less. In the event the above 10-day maximum drawdown requirement is impractical, the owner and design engineer may alternatively design the flood storage pool equivalent to the volume which would result from two 100-Year Storm events, and provide a drawdown system capable of removing the volume from one 100-Year Storm event in 30 days or less. The 100-Year Storm Event should be preceded within 5 days by a 25-Year Event, at a minimum, to pre-wet the drainage and provide realistic runoff volumes for the larger event.
    A. The owner/designer must evaluate and design a reliable drawdown system based upon an integrated system which includes the reservoir, direct precipitation runoff, runoff from adjacent drainage areas, and the presence and effectiveness of diversion facilities.

    B. The alternate storage area designated to hold fluids transferred from the reservoir during the drawdown periods must also have all permits required by appropriate regulatory agencies. If the alternate structure is a jurisdictional dam it must also be designed and constructed to the same ADWR standards as the primary storage facility.

APPENDIX

TECHNICAL APPROACH
FOR
DETERMINING REQUIRED FLOOD PROTECTION FOR HIGH AND SIGNIFICANT HAZARD POTENTIAL DAMS CONSTRUCTED WITH NO SPILLWAYS

I. DETERMINING THE MINIMUM ELEVATION OF THE DAM CREST

A. The minimum elevation of the dam crest must be determined to comply with the two following requirements:

1. The dam must provide the required Maximum Reservoir Storage (MxRS) storage for the maximum combination of antecedent reservoir conditions and runoff from the PMF, and

2. The dam must provide the required minimum freeboard of the dam crest above the maximum reservoir elevation.

The Minimum Dam Crest Elevation (MDCE) is equal to the Maximum Reservoir Elevation (MxRE) plus the minimum dam crest freeboard (FB) (ie. MDCE = MxRE + FB). The Maximum Reservoir Elevation (MxRE) is derived from the calculated required Maximum Reservoir Storage (MxRS) volume entered into the Dam Elevation - Reservoir Storage Curve. The minimum dam freeboard shall be as required in the guideline.

B. The Maximum Reservoir Storage (MxRS) can be derived using one of two alterative approaches:

1. MONTHLY APPROACH: A monthly approach to determine the Maximum Reservoir Storage (MxRS) is described below. A general example of the several curves described below are attached to this appendix.

a. Develop the Reservoir Water Balance Storage Curve. This curve is defined as the design maximum monthly antecedent condition in the reservoir. This curve is derived by plotting the design Monthly Reservoir Water Balance Storage (Mn_{1-12}RWBS) for each month of the year. The Monthly Reservoir Water Balance Storage (Mn_{1-12}RWBS) equals the total of the monthly minimum volume required for the maximum-operation-stage of the facility, plus other items including the monthly runoff for the design wet year, minus the evaporation, and minus other water consumption/loss factors.

b. Develop the Reservoir PMF Storage Curve. This curve is developed by plotting the calculated runoff which must be stored for each monthly PMP value (Mn_{1-12}PMFS) based on information provided in HMR-49.

c. Develop the Maximum Reservoir Storage Curve. This curve is obtained by plotting the Monthly Maximum Reservoir Storage (Mn_{1-12}MxRS) for each of the 12 months.

The Monthly Maximum Reservoir Storage ($Mn_{1-12}MxRS$) equals the total of the Monthly Reservoir Water Balance Storage ($Mn_{1-12}RWBS$) plus the corresponding Monthly Reservoir PMF runoff volume ($Mn_{1-12}PMFS$) (ie. $Mn_{1-12}MxRS = Mn_{1-12}RWBS + Mn_{1-12}PMFS$).

d. Determine the Maximum Reservoir Storage (MxRS). The Maximum Reservoir Storage (MxRS) equals the largest total monthly storage value adding the Monthly Reservoir Water Balance Storage ($Mn_{1-12}RWBS$) plus the Monthly PMF runoff volume ($Mn_{1-12}PMFS$)(ie. $MxRS = MxMn_{1-12}RS = Mx(Mn_{1-12}RWBS + Mn_{1-12}PMFS)$).

e. Plot the Monthly Maximum Reservoir Storage data ($MxMn_{1-12}RS$) for the dam to obtain the Maximum Reservoir Storage Curve. Plotting the Maximum Reservoir Storage Curve on the same graph as the Reservoir Water Balance Storage Curve allows compairson of the two curves and the monthly variation in the maximum reservoir storage to provide flood storage in addition to the antecedent storage.

2. ANNUAL APPROACH: An annual approach to determine the Maximum Reservoir Storage (MxRS) is described below.

a. Develop the anticipated Maximum Month Reservoir Storage required for the design year water balance storage ($MxMn_{1-12}RWBS$) and add the storage required for the runoff volume from the Maximum Month PMF ($MxMn_{1-12}PMFS$) (ie. $MxRS = MxMn_{1-12}RWBS + MxMn_{1-12}PMFS$). The Maximum Allowable Reservoir Elevation or Rule Curve would equal the elevation corresponding with the Maximum Reservoir Storage.

C. Determine the Minimum Dam Crest Elevation (MDCE). The minimum elevation of the dam crest is determined by entering the Maximum Reservoir Storage (MxRS) volume into the Dam Elevation - Reservoir Storage Curve to obtain the Maximum Reservoir Elevation (MxRE), and adding the minimum dam freeboard (FB) (ie. MDCE = MxRE + FB).

II. DETERMINING THE RESERVOIR RULE CURVE

A. A Reservoir Rule Curve which is equivalent to the Maximum Allowable Reservoir Elevation Curve must be developed for the reservoir. The Reservoir Rule Curve defines the maximum reservoir level allowed in order to maintain the required flood pool storage plus the dam freeboard.

B. The following discusses a monthly approach to developing the Reservoir Rule Curve (Maximum Allowable Reservoir Elevation Curve) for operations to provide for flood pool storage and freeboard below the dam crest:

a. Obtain the Monthly Maximum Allowable Reservoir Storage ($Mn_{1-12}MxARS$) volume by subtracting the required flood storage value equivalent to the Monthly PMF runoff volume ($Mn_{1-12}PMFS$) from the Maximum Reservoir Storage (MxRS) volume (ie. $Mn_{1-12}MxARS = MxRS - Mn_{1-12}PMFS$).

b. Enter the Monthly Maximum Allowable Reservoir Storage (Mn_{1-12}MxARS) volume for each month into the Dam Elevation - Reservoir Storage Curve to obtain the Monthly Maximum Allowable Reservoir Elevation data (Mn_{1-12}MxARE); and

c. Plot the Monthly Maximum Allowable Reservoir Elevation data (Mn_{1-12}MxARE) for each month of the year to define the Maximum Allowable Reservoir Elevation Curve; this curve is equivalent to the Reservoir Rule Curve for the dam.

C. Plot the Reservoir Rule Curve on a separate graph which includes the Minimum Dam Crest Elevation, the Maximum Reservoir Elevation, and identify the interval between the dam crest and the Maximum Reservoir Elevation as the required minimum freeboard. It is also informative to plot on the same graph the design Reservoir Water Balance Elevation Curve and the Maximum Reservoir Elevation Curve. This complete plot of the developed information allows comparison of the Reservoir Rule Curve (Maximum Allowable Reservoir Elevation) for any month (Mn_{1-12}MxARE) with the corresponding month for either the anticipated Maximum Reservoir Elevation (Mn_{1-12}MxRE) or the design Reservoir Water Balance Elevation (Mn_{1-12}RWBE).

The Maximum Reservoir Elevation Curve is developed by converting the monthly Maximum Reservoir Storage Curve data (Mn_{1-12}MxRS) to monthly Maximum Reservoir Elevation data (Mn_{1-12}MxRL) using the Dam Elevation - Reservoir Storage Curve. The converted elevation data is then plotted for the twelve months of the year.

The design Reservoir Water Balance Elevation Curve is developed by converting the monthly Reservoir Water Balance Storage Curve data (Mn_{1-12}RWBS) to monthly Reservoir Water Balance Elevation data (Mn_{1-12}RWBL) using the Dam Elevation - Reservoir Storage Curve. The converted elevation data is then plotted for the twelve months of the year.

- END OF GUIDELINE -