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DENVER, COLORADO

CRITERIA AND GUIDELINES FOR EVACUATING STORAGE RESERVOIRS AND SIZING LOW-LEVEL OUTLET WORKS

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PREFACE

The determination of reservoir evacuation rates, initial filling rates, and the sizing of low-level outlet works are important design considerations for storage dams. This document presents Bureau of Reclamation policy pertaining to requirements for evacuating storage reservoirs and for sizing low-level outlet works.

Outlet works and their controls are designed to meet several requirements. These include: (1) project operational requirements as dictated by downstream irrigation and water supply demands, flood control regulation, sediment accumulations, and requirements for recreation, fish and wildlife enhancement, navigation, water quality, and releases to satisfy downstream water rights; (2) meeting or supplementing diversion requirements during construction; (3) evacuation of the reservoir if emergency conditions occur, or inspection, maintenance, and repair of the dam and appurtenant works that are normally submerged; and (4) controlling the rate of reservoir rise as required by reservoir filling criteria.

This two-part document addresses evacuation rates and facilities. Part I contains evacuation criteria for Bureau of Reclamation storage reservoirs. Part II contains guidelines which provide methods of evaluating site-specific conditions in compliance with the Bureau of Reclamation's criteria.

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I. CRITERIA FOR EVACUATION OF STORAGE RESERVOIRS

A. General Criteria

Water release facilities are provided for diversion during construction, meeting water delivery needs of the project, controlling the reservoir during initial filling, and aiding in flood routing. To accomplish the evacuation and initial filling objectives, the following criteria should be followed:

1. All water release facilities, including outlet works, gated spillways, and power penstocks should be considered available for evacuation to the extent that their reliability in an emergency situation can be reasonably certain. In the case of canal outlet works, there must be a positive means of making releases to a natural watercourse by use of a bypass or wasteway in order for such outlet works to be considered available for emergency releases. In the case of powerplants, more than one unit must be installed and operational, and generally only 50 percent of the release capability (as defined by the turbine discharge curves) should be considered available because some units could be inoperable when their discharge capacity is needed. For powerplants with four or more generating units, more than 50 percent of the turbine discharge capacity may be used if supported by historical operations data. When turbine capacity is used, care should be taken to ensure that the power distribution system will be able to accept the electricity which will be generated. Bypass outlet works for powerplants may be used if they are isolated from the turbines by gates or valves. Any site-specific, reasonable combination of available facilities can be used to meet evacuation criteria cited herein.

2. Low-level outlet works should be located and sized to provide discharge capacity sufficient to evacuate the reservoir in accordance with table 4 and to maintain the reservoir filling rates specified in the initial filling criteria.

3. The initial reservoir water surface elevation to be used for performing evacuation computations depends upon storage allocations and project needs. Normally, one of the

following three elevations should be selected as the initial reservoir level for determining evacuation requirements:

a. The top of joint-use capacity if a reservoir's capacity is assigned to flood control during certain periods of the year and to conservation during other periods of the year.

b. Top of the active conservation capacity when the reservoir does not have joint-use or exclusive flood control storage.

c. Other initial reservoir elevations may be selected only if reservoir operation studies show a level which is more appropriate. For example, the starting reservoir elevation for a reservoir which has never filled over an extended period may be considered to be the maximum elevation to which the reservoir has risen. Reservoir elevations selected on the basis of operation studies shall be conservative estimates and shall not be simple mean reservoir elevations.

4. Reservoir inflows for the period of evacuation or initial filling shall be based on the following methods of analysis of the stream flow records for the reservoir. If adequate streamflow records are not available for the reservoir, records from nearby stations should be adjusted in accordance with appropriate hydrologic procedures for use in the analysis.

Evacuation. - The inflow for analysis purposes shall be the highest consecutive mean monthly streamflows for the computed evacuation period. This method will sometimes require several iterations to arrive at an evacuation time which is in agreement with the time upon which the inflow was based. If the solution does not converge on a single evacuation time, the evacuation time shall be the longer of the evacuation times.

Initial Filling. - Inflows for initial filling shall be based on a combination of base flow and a frequency flood event. If the selected frequency flood includes base flow, average monthly streamflow should not be added to the hydrograph. Base flow should be the average of the mean monthly streamflow for the anticipated filling period. Generally, the selected frequency flood will have a return period of five times the length of the filling period with a minimum return period of 5 years.

5. Table 1 contains reservoir allocations that should be considered initially filled with water in computing evacuation periods.

Table 1. - Reservoir allocation volume to be considered in computing evacuation periods

Reservoir Allocation	**Volume considered**
Exclusive flood control*	Generally none
Joint use	All
Active conservation	All
Inactive	All except sediment accumulations
Dead	None

* Reservoir regulation procedures usually require evacuation of exclusive flood control space as rapidly as downstream channel capacity will permit to provide space for control of recurring flood events. Therefore, the exclusive flood control allocation space is generally not used in the evacuation analyses. In cases where there is only an emergency spillway or no spillway, it may be necessary for the evacuation analyses to consider flood surcharge space.

6. Criteria for evacuation should recognize site-specific conditions, economic aspects, and project needs to provide an acceptable balance between costs and rates of evacuation and filling. Evacuation time established for design should consider downstream channel capacity, level of risk to the dam, hazard potential to the downstream areas, and the ability to mitigate downstream hazards with warning systems when possible. In general, low-level outlet works in

conjunction with other release facilities should be located and sized to draw down the reservoir, within a period of 1 to 4 months, to the lower of the following levels:

a. A reservoir level commensurate with a storage capacity that is 10 percent of that at the initial reservoir level.

b. A reservoir level which is less than 50 percent of the hydraulic height[1] of the dam.

The guidelines established in part II of this document should be used to evaluate site-specific conditions in compliance with the general criteria.

B. <u>Design Requirements for Low-level Outlet Works</u>

Sizing of outlet works should consider the following:

1. Release requirements to meet project needs

2. Economic benefits that can be derived by using the outlet works in routing the inflow design flood

3. Satisfaction of evacuation criteria

4. Economic benefits that can be derived by using the outlet works for diversion of streamflows during construction

Low-level outlet works should be designed to satisfy the following requirements:

1. Low-level outlet works should be located to ensure that the major portion of the reservoir storage volume can be evacuated by gravity flow.

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[1]Hydraulic height is defined as the height to which the water rises behind the dam, and is the difference between the lowest point in the original streambed at the axis or the centerline of the dam and the maximum controllable water surface.

2. The sill elevation of the intake structure should be set above the predicted 100-year sediment accumulation level or a multiple-level intake structure should be provided to prevent the outlet works from being plugged by sediment during the life of the project.

3. Geologic factors should be considered in locating low-level outlet works to ensure that the outlet works does not become blocked as a result of landslides, ensuring that the capability to evacuate the reservoir is preserved.

4. Outlet works which are to be used for evacuation and control of reservoir levels during initial filling should be in operable condition as required by the initial filling plan so that filling rates can be satisfied and emergency evacuation can be accomplished. The final closure should be timed to minimize the risk of flood flows occurring while postdiversion construction is being performed in waterways. Requirements with respect to operability of the outlet works should be given in the construction specifications.

5. The initial filling criteria, DOC (Designers' Operating Criteria), and SOP (Standing Operating Procedures) should be completed before initial filling and should contain requirements for periodic inspection and exercising of low-level outlet gates and valves to ensure their proper operation. The initial filling plan should take into account completion of second-stage construction where the outlet works are used for diversion.

C. Deviation From General Criteria

The criteria and guidelines presented in this document should be applied to the majority of storage reservoirs. It may be impractical to provide the drawdown capability to meet the criteria and guidelines for certain projects. Some reservoirs may be too large for short term evacuation or too small to limit the rate of water surface rise during initial filling and some may have unique functions or other site-specific conditions which justify deviation from established criteria and guidelines. When specific project conditions require a drawdown capacity which does not meet the criteria and guidelines contained in this document, the following information should be presented in the technical memorandum describing the basis for locating and sizing the outlet works.

1. The rate of water surface rise during initial filling period using the maximum discharge capacity of the proposed release facilities.

2. The evacuation period resulting from using the maximum drawdown capability of the proposed release facilities.

3. Information on the reservoir level and corresponding storage volume at the end of the drawdown period specified in these guidelines.

4. The size of low-level outlet works that would be required to meet the established criteria and guidelines and the associated costs. If the costs cannot be justified, alternative operational plans consistent with requirements for water deliveries to users, such as changing the initial filling period to avoid periods of high inflow to the reservoir, should be considered and documented.

D. Criteria for Existing Reservoirs

The evaluation of an existing dam with respect to the adequacy of low-level outlet works should be based on the criteria presented within this document. The evaluation should consider the reliability and present conditions of the dam, outlet works, reservoir, and flood plain downstream from the dam. Recommended corrective actions will be considered on a case-by-case basis depending on site-specific conditions. Generally, unless modifications can be accomplished at relatively little expense, existing structures will not be recommended for corrective action for the sole purpose of meeting evacuation criteria. However, when modifications are proposed to a waterway of an existing structure with inadequate evacuation capacity, the designs shall provide for increased evacuation capacity to the extent that this can be achieved at reasonable incremental cost.

Evacuation capacity which is less than that required by this criterion may be accepted for an existing structure for two reasons. First, the risk associated with the first filling of the reservoir has passed. Secondly, the cost of increasing evacuation capacity for an existing structure may be orders of magnitude greater than the incremental cost of increasing evacuation capacity in the design of a new structure. The risk reduction resulting from increased outlet capacity at an existing dam is generally not sufficient to justify the cost of modifications.

When a structure is identified as having inadequate evacuation capability, appropriate segments of the organization shall be notified to ensure proper awareness of the situation. If identified during the SEED/SOD (Safety Evaluation of Existing Dams/Safety of Dams) process, this notification can be accomplished by inclusion of the findings in any of several SEED/SOD process reports. The SEED analysis summary would be an appropriate location for documentation of this decision. Otherwise, the notification shall be by an ACER-signed (Assistant Commissioner -Engineering and Research) memorandum to the Regional Engineer with copies to appropriate Denver Office dam safety, design, and operation and maintenance personnel. The documentation should identify the actual time which would be required to evacuate the reservoir and state that any future modifications to the outlet works should include evaluations for increased evacuation capability. If evacuation is limited by downstream release restrictions, the documentation should also include the required evacuation time using the full capacity of the outlet works.

II. GUIDELINES FOR DETERMINING EVACUATION RATES FOR STORAGE RESERVOIRS

The following guidelines provide suggested methods of evaluating site-specific conditions for the determination of evacuation and initial filling rates in compliance with the criteria stated in part I of this document.

A. Reservoir Evacuation Rates Based on Project Conditions

This section presents general guidelines on ranges of evacuation periods for storage reservoirs based on the level of risk and hazard potential at each site. Risk is the probability of occurrence of an adverse event. Hazard is the consequence of having an adverse event.

The presence of adverse conditions at a site introduces an element of risk which should be reduced to a reasonably low level by provisions in the design. In cases where site conditions are particularly adverse, such as where active faults are present in a foundation, a small risk will probably remain after defensive measures are taken. Hazards pertain to potential loss of human life and property damage in the area downstream from the dam in the event of failure or improper operation of the dam or appurtenant facilities. Hazard potential is based on location rather than on structural integrity.

For the purpose of evaluating reservoir evacuation periods, assignment of a level of risk and classifying downstream hazard potential are, by nature of the problem, quite subjective. Consequently, the terms high, significant, and low are assigned to the risk and hazard potentials. The hazard potential classification given to Reclamation dams is based on the guidelines provided in table 2.

Table 2. - Downstream hazard classification system

Classification	Population at risk	Economic loss
Low	0	Minimal (undeveloped agriculture, occasional uninhabited structures, or minimal outstanding natural resources)
Significant	1-6	Appreciable (rural area with notable agriculture, industry, or work sites, or outstanding natural resources)
High	More than 6	Excessive (urban area including extensive community, industry, agriculture, or outstanding natural resources)

Risk is more difficult to classify than hazards because of the many combinations and adverse conditions that may be involved at a particular damsite. The elements of risk or risk factors can be identified and a rational, but not exact, classification can be made. The elements of risk or risk factors which should be considered in risk classification are listed in table 3.

Table 3. - Elements of risk for dams

<u>Hydrologic factors</u>

- Floods exceeding those used for design
- Uncertainty of flood estimation
- Ratio of flood to storage volumes in the reservoir
- Reservoir sediment deposition potential

<u>Geologic factors</u>

- General foundation conditions
- Seismicity of site
- Faulting at site
- Liquefaction potential of dam and foundation
- Rock condition (fractures, shear zones, relief jointing, solubility)
- Seepage potential

<u>Structural factors</u>

- Dam type and design
- Unprecedented size
- Unusual complexity
- Age and condition

<u>Construction and material factors</u>

- Construction material characteristics such as permeability, erodibility, and strength
- Quality of construction

<u>Operating factors</u>

- Remoteness and accessibility of site
- Training and experience of operating personnel
- Reliability of commercial and auxiliary power
- Complexity of equipment and operating procedures

Certain elements stand out which would justify a high-risk classification, such as:

* Active faults in or near a dam foundation
* Possibility of foundation displacements during a major earthquake event
* High probability of hurricane or flash floods
* High potential for foundation liquefaction
* High potential for rock solutioning
* High potential for piping
* Exceptionally poor construction materials
* Severe deterioration of structural elements
* Poor quality control of construction

At the other end of the classification scale would be an absence of all such adverse conditions. Defining the "significant" classification is much more difficult for risk than it is for hazard potential. This middle range is a very important one because it deals with the broad range between extremes where many dams normally fit.

A general guide for determining emergency evacuation periods is established in table 4. These values are based on Bureau of Reclamation experiences which reflect a reasonable balance between risks, hazards, and costs. Table 4 lists a rather wide range of classification possibilities and ranges of evacuation periods for four reservoir stages. The suggested evacuation periods, which are considered to be conservative, may be adjusted on the basis of detailed studies and evaluations which should take into account all important site-specific conditions that have a rational bearing on evacuation periods based on the risk and hazard potential addressed in this subsection (II.A). It is desirable for a reservoir to meet the evacuation time requirements for all four stages shown in table 4. However, intake elevations of release facilities at a specific dam may limit evacuation to a certain elevation. Consequently, the values provided for 25 percent of the hydraulic height should be used only as a guide when physically possible.

B. <u>Initial Reservoir Filling Rate</u>

Initial reservoir filling is the first test of a dam to perform its intended functions. While initial filling criteria may be established after construction of a dam has been initiated, sizing of the outlet works to meet probable outflow requirements during initial filling must be accomplished during design. Consequently, desired rates of pool rise must be determined at the time design requirements are established.

In order to monitor dam and reservoir performance, the rate of filling should be controlled to the extent feasible to allow for accomplishing a predetermined monitoring program as prescribed in the Bureau of Reclamation, Assistant Commissioner - Engineering and Research Memorandum, "Guidelines for Preparing Reservoir Filling Criteria, Bureau of Reclamation Dams and Reservoirs," DES-2, June 1989.

Low-level outlet works should be located and sized in combination with other outlets to provide discharge capacity sufficient to maintain the reservoir filling rates specified by the initial filling criteria and to hold reservoir levels reasonably constant for elevations above 50 percent of the hydraulic height of the dam for the established inflow conditions.

Inflow into the reservoir during initial filling should be assumed as a reasonable frequency flood plus the average of the mean monthly inflows for the selected filling period. This frequency flood should generally be approximately 5 times the duration of the filling period. For example, a reservoir which is small enough to fill in 1 year under mean inflow conditions might require outlets sized to pass a 5-year flood, in addition to mean inflow. A large reservoir requiring 5 years to fill might require outlets sized to pass a 25-year flood, in addition to mean inflow. Both of these examples will result in about a 20-percent chance of exceeding capability to control pool levels to the desired rate of rise during their filling periods.

Table 4.- General guide for determining emergency evacuation time (in days)

Evacuation stage	High hazard, high risk	High hazard, significant risk	High hazard, low risk	Significant hazard, high risk	Significant hazard, significant risk	Significant hazard, low risk	Low hazard, high risk	Low hazard significant risk	Low hazard, low risk
75% Height*	10-20	20-30	30-40	20-30	30-40	40-50	40-50	50-60	60-90
50% Height*	30-40	40-50	50-60	40-50	50-60	60-70	60-70	70-90	90-120
10% Storage**	40-50	50-60	60-70	50-60	60-70	70-80	70-80	80-120	120-160
25% Height*	60-80	70-90	80-100	70-90	80-100	90-110	90-110	100-160	150-220

* Height is measured from the initial pool as defined in subsection A.3 of part I for determining evacuation requirements.

** Reservoir storage between original streambed and the initial reservoir water surface level as defined in section A.3 of part I for determining evacuation requirements.

C. Estimating Mean Reservoir Inflows for Evacuation Studies

Inflow into the reservoir should be based on the highest consecutive mean monthly inflows for the duration of the evacuation period. For existing Storage Reservoirs, this information is readily available in the "Annual Water Supply Report." At sites where this information is not readily available, appropriate studies should be conducted to estimate the mean monthly inflows. The following process should be followed in estimating inflows and conducting evacuation studies:

1. Obtain mean monthly inflows for the site

2. Make an initial estimate of the required evacuation period

3. Create inflow hydrograph using the highest consecutive mean monthly inflows for the duration of the evacuation period

4. Perform flood routing to determine evacuation period

5. Compare the computed evacuation time to the length of the inflow hydrograph

6. If the computed evacuation period would change the inflow hydrograph, return to step 3. Otherwise document the results.

The following example demonstrates this process for Deer Creek Reservoir:

1. Mean monthly inflows were obtained from the "Annual

Water Supply Report" and are summarized as follows:

Month	Mean Monthly Inflow (acre-ft)	Mean Monthly Inflow (ft^3/s)[2]
Oct.	13,300	216
Nov.	16,500	277
Dec.	16,700	272
Jan.	15,800	257
Feb.	15,200	274
Mar.	18,900	307
Apr.	29,900	503
May	64,400	1,047
June	62,600	1,052
July	20,400	332
Aug.	12,100	197
Sep.	10,100	170

2. An initial estimate was made of 150 days to evacuate the reservoir

3. The following inflow hydrograph was created to reflect the highest five consecutive mean monthly inflows (Mar., Apr., May, June, and July):

Time	Inflow (ft^3/s)
0	307
day 10	307
day 20	307
day 31	307
day 32	503
day 40	503
day 50	503
day 61	503
day 62	1,047
day 70	1,047
day 80	1,047
day 92	1,047
day 93	1,052
day 100	1,052
day 110	1,052
day 122	1,052
day 123	331
day 130	331
day 140	331
day 150	331

[2] Inflow (ft^3/s) = [Inflow in acre-ft/No. days in the month] x [43,560/(24x3,600)]

4-5. After running the flood routing, one would find that the inflow hydrograph is not long enough to evacuate the reservoir.

6. Because the reservoir is not adequately evacuated with this length of inflow hydrograph, return to step 3 and lengthen the hydrograph with the prior or subsequent month with the highest inflow (i.e., February).

Note that obtaining an inflow hydrograph which is consistent with the evacuation time may require several iterations.

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