DAM SAFETY
PROJECT REVIEW GUIDE

[WEB PAGE VERSION]

September 23, 1994
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(SUPERSEDES "Project Review Guide," Revised May 16, 1996)

This Guide is Subject to Change.
Prior to beginning a new project, call the office of the State Engineer for status of updates.

303-866-3581

Dam Safety Branch
Division of Water Resources
Office of the State Engineer
Department of Natural Resources
Denver, Colorado

PURPOSE OF THE DAM SAFETY PROJECT REVIEW GUIDE

This document has been created to provide a technical guide for the engineering community involved with the design of dams under the Colorado Statutes and the "Rules and Regulations for Dam Safety and Dam Construction." In addition, this guide has been written to help the engineer follow the rules for a specific project. The guide is divided into three parts plus references.

Part I - ADMINISTRATIVE REQUIREMENTS: Lists the required documents, description of the documents, and fees associated with filing an application to build, repair or to modify a jurisdictional dam in Colorado.

Part II - DESIGN AND TECHNICAL CRITERIA: Outlines, clarifies, and supplements the technical requirements of the Rules and Regulations.

Part III - CONSTRUCTION: Provides information concerning expectations for monitoring, recording and documenting the construction of any work on a dam.

No document can be inclusive of all design problems confronted by an engineer, nor can it be expected to foresee future changes to law and rules. In addition, no guide can be a substitute for sound engineering judgment or experience. Therefore, this guide is subject to change as improved techniques and policies become known.

Because this a guide for the engineering community, suggestions and comments for additions and changes are welcome at any time. Please write or call the following:

Colorado Division of Water Resources
Dam Safety Branch
1313 Sherman Street Rm 818
Denver, Colorado 80203
303-866-3581

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PART I

ADMINISTRATIVE REQUIREMENTS

A. FILING AN APPLICATION:

1. Preliminary Filing: The documents listed below must be submitted as an application for approval to construct a new jurisdictional dam or enlargement in Colorado (only applicable documents are required for repairs or modifications to existing dams See Rule 6.A.). The various reports may be submitted in a single bound document.

a.	Application Form	1 each
b.	Construction Plans (24x36 prints)	1 each
c.	Construction Specifications	1 each
d.	Classification Report	2 each
e.	Hydrology Report	2 each
f.	Geotechnical and Structural Analysis Report	2 each
g.	Design Report	2 each
h.	Instrumentation and Monitoring Plan	2 each
i.	Detailed Cost Estimate (include in design report)	
j.	Filing Fee	1 check

(NOTE: Additional copies of reports, drawings and specifications may be requested by the State Engineer as required.)

2. Supplemental Filing: If any minor corrections are required to the application, the engineer should submit the following items:

   a. Corrected documents as per review memo .
   b. Revised cost estimate, if change occurs.

3. Final Filing: Once a design is considered acceptable for construction, the design engineer will be notified to submit the final documents consisting of the items listed below. Approval will occur as quickly as possible after the final documents have been received.

   a. Two copies of any corrected report documents.
   b. Only the final mylar cover sheet drawing (24x36).
   c. Four complete sets of blue/black prints (24x36).
   d. A minimum of five sets of specifications.

B. DOCUMENT DESCRIPTIONS

1. Application Forms: Application forms are available at no cost from the State Engineer. There are three different forms. One for each type of work an owner may expect to perform on a jurisdictional dam. (Copies are found under forms) They are:

a. Application for the review of plans and specifications for the construction or enlargement of a reservoir dam.

b. Application for the review of plans and specifications for the alteration, modification, or repair of a reservoir dam.

c. Application for removal or breach of a reservoir dam.

2. Construction Plans (Drawing Standards): (See Rule 5.A.(2))

a. The plans shall show the design of the dam and each appurtenant structure in sufficient detail so that the contractor or builder is able to construct the structure from the plans and specifications. Record drawings filed with the State Engineer shall be originals, or a high quality reproducible archival copy of the original, and shall be prepared in an appropriate scale so details are legible, drawn with permanent ink on high quality Mylar or equivalent, submitted in an overall size of 24 inches high and 36 inches wide. Size limits are required due to the book and cabinet filing system used.

b. Drawings shall have a minimum margin of two (2) inches for binding on the left side (24-inch edge) and a 1/2 inch margin on the right, top and bottom edges.

c. MINIMUM size letters shall be 1/8 inch, or Leroy 100 template or equivalent. This permits readable reduced drawings made from microfilm documents.

d. All drawing sheets shall have bar scales in order to allow scaling of reduced drawings.

e. Each sheet shall have in the lower right-hand corner a 1/2 inch by 3 inch space for the State Engineer's file number.

f. Use of the Professional Engineer Seal on reproducible drawings is in a state of administrative flux. Until final rules by the Board of Professional Engineers are promulgated, the acceptable alternative is described below in I.B.2.h.(7).

g. Each sheet shall be numbered sequentially with the first or cover sheet being sheet number one in conjunction with the total number of sheets in the plan set; e.g., "Sheet 1 of 6".

h. The front cover sheet, Sheet 1, shall show as a minimum, the following information:

(1) Title or name of the dam (use the official record name).

(2) The name of the owner.

(3) Drawing index including drawing title and drawing number as described in B.2.g. above.

(4) Water Division ____, Water District__

(5) County where dam is located.

(6) Vicinity map showing location of dam.

(7) Responsible design engineer's printed name, PE number, and signature shown in lower right 1/4 of drawing. Format as follows:

(signature) **Colo. PE No______**
(printed name of engineer)

(8) State Engineer's approval statement:

Approved on the ______day of __________,20__.

____
State Engineer

By: ________________________
Assistant State Engineer

(9) Provide space near lower right-hand corner for adding "AS-CONSTRUCTED" statement as follows:

"These plans represent the AS-CONSTRUCTED conditions of ________dam to the best of our knowledge and judgement, based in part on information furnished by others as of the ___day of __________, 20__

(signature) Colo PE No______
(printed name of engineer)

3. Construction Specifications Standards (See Rule 5.A.(3))

a. Cover sheet shall show at least the following:

(1) Title or name of dam (identical to plans).

(2) Water Division ___, Water District __

(3) County.

(4) Design engineer's seal and signature (as required by CRS 12-25-117)

b. The title page or first sheet behind the cover shall show as minimum the following:

(1) Title or name of dam (identical to plans).

(2) Water Division ___, Water District __

(3) County.

(4) Design engineer's seal and signature (as required by CRS 12-25-117)

(5) State Engineer approval

Approved on the _____ day of __________, 20 __

____
State Engineer

By: ________________________
Assistant State Engineer

c. The specifications shall be indexed.

d. Final specifications shall be submitted on a good grade of white 8-1/2" X 11" paper.

e. Each set of specifications filed shall be bound, and shall include ONLY the technical specifications and other information required herein. PLEASE DO NOT include contract administration documents such as notice to bidders, bid bond, equal opportunity, etc.

f. The General Conditions section of the specifications shall include the following statement that:

> "Approved plans and specifications shall not be materially changed without the prior written approval of the State Engineer," AND
>
> "The State Engineer has the authority to require the material used and the work of construction to be accomplished according to rules and regulations and that construction shall not be considered complete until the State Engineer has accepted the same in writing." AND
>
> "The owner's engineer will monitor the quality of construction as specified in Rule 9 of the Rules and Regulations for Dam Safety and Dam Construction, September 30, 1988."

4. Hazard Classification Report: The classification report is generally the first document prepared since the design standards are driven by the consequences of a dam failure. This report may be submitted to the State Engineer for an opinion prior to beginning the design phase. The report shall be indexed and bound. A filing fee is not required. The standards and criteria for the analysis are found in this guide in PART II.A. Hazard Classification. See Rules and Regulations, Rule 5.A.(4).

5. Hydrology Report: The hydrology report provides the basis for approving the size of a reservoir dam spillway. Standards and criteria used by this office for review and analysis are found in PART II.B - Hydrologic Design. The report shall be indexed and bound. This report may be submitted for an opinion of the State Engineer before filing an application for approval. A filing fee is not required. See Rules and Regulations, Rule 5.A.(5).

6. Geotechnical and Structural Analysis Report: This report contains the information concerning the geology, seismicity, and

investigation of the soil strength properties from field and laboratory tests and the availability of materials to assure the dam can be constructed as designed and approved. It also includes a definitive analysis of the stability of the dam during the different loading conditions which the dam may be subjected to. The standards and criteria are found in PART II.C - Geotechnical Investigation and Design. The report shall be indexed and bound. See Rules and Regulations, Rule 5.A.(6).

7. Design Report: The intent of the Design Report is to provide a narrative of the engineer's design philosophy and the methods used to design the various components of the dam not discussed in other reports. When copies of the calculations, assumptions, and applicable references are included, a record of design is established and the review process is made easier. The report shall be indexed, legible, and clearly documented. Controversial designs and new concepts should be documented and accompanied with a the calculations and a copy of the pertinent parts of the references which support the design. No further discussion within this guide is provided for this report. See Rules and Regulations, Rule 5.A.(7).

8. Instrumentation and Monitoring Plan: The minimum requirements are found in the Rules and Regulations for Dam Safety and Dam Construction, however, "PART II.H - Instrumentation Plan" and "PART II.I - Monitoring Plan" provide more definitive recommendations and reporting format. See Rules and Regulations, Rule 5.A.(8).

9. Cost Estimate: A detailed estimate of cost of the construction including engineering fees shall be provided. This is normally incorporated in the Design Report. The State Engineer recognizes the sensitivity of this information until the construction bid date has closed. For record purposes the files are not considered public until after a construction contract has been awarded or after the expiration of the plans and specifications in five years. See Rules and Regulations, Rule 5.A.(9).

10. Filing Fee: Effective 1 July 1990, CRS 37-80-110 requires a fee of $3.00 per $1000.00 of construction costs including the engineering fees. The minimum fee is $100.00 and the maximum fee is $3000.00. The check should be made payable to the STATE ENGINEER. See Rules and Regulations "Supplement, Paragraph 3. FEES FOR RESERVOIR DAMS."

PART II

DESIGN AND TECHNICAL CRITERIA

A. HAZARD CLASSIFICATION AND SIZE OF DAM:

1. Purpose: The purpose of the Hazard Classification Study is to evaluate the potential consequences of the subject dam failure on residents and property below the dam and to identify the standards for the investigation, design, and construction which apply to the proposed project. The purpose of the size determination is to apply the appropriate design standards to the project.

2. Criteria for Hazard Classification

a. The hazard class is based upon following assumptions:

(1) The dam fails by erosion of embankment materials initiated by piping, embankment slides or deterioration of the outlet works.

(2) At the time of failure, reservoir waters are stored to the crest of the emergency spillway.

(3) The dam fails at the maximum section. A reservoir with multiple dams must be analyzed as separate structures. Design standards of the maximum hazard class applies to all embankments.

b. Because of the sensitivity of the time for a dam to completely fail, several reasonable failure rates should be considered. This is especially important if there is a range of reasonable failure rates which would cause a dam to be considered for either of two hazard classifications depending upon the selected failure rate.

c. If the analysis shows loss of life is expected, the dam is classified as Class I. Use of the flood plain by occasional campers and fishermen is not controlling for these analyses, since these individuals are expected to be warned by rising waters and to flee for their lives.

However, the existence of a large established campground adjacent to the stream should be considered for Class I. No loss of life is expected to occur if the increased depth of flow is two feet or less and the product of the average flood plain flow velocity and the depth of flow at a critical area is less than seven. If the failure of the subject dam can cause the failure of another Class I dam located downstream, the dam is automatically considered Class I. Should no loss of life be expected, the next question of concern is property damage.

d. A Class II dam is a dam for which significant damage is expected to occur, but no loss of human life is expected in the event of failure of the dam. Significant damage is defined as damage to structures where people generally live, work or recreate, or damage to public or private facilities exclusive of unpaved roads and picnic areas. Damage means rendering the structure uninhabitable or inoperable. It is presumed that damage is expected to occur when a structure is in more than two feet of water, or the product of the water depth and the average flood plain flow velocity is greater than seven. A detailed analysis of damage to each structure may be made as an alternative to the above presumptions.

e. A Class III dam is one for which no loss of human life is expected, and damage to structures and public facilities as defined for a Class II dam is not expected in the event of a failure of the dam.

f. A Class IV dam is a dam for which no loss of human life is expected, and which damage will occur only to the dam owner's property in the event of failure of the dam.

g. In some cases, a classification study may require an analysis of floods across the state line.

3. Criteria for Size of Dam

a. A "Minor Dam" does not exceed 20 feet in vertical height and 100 acre-feet in capacity.

b. A "Small Dam" is greater than 20 feet in vertical height but equal to or less than both 40 feet and 1,000 acre-feet in capacity, or is greater than 100 acre-feet but equal to or less than both 1,000 acre-feet in capacity and 40 feet in vertical height.

c. An "Intermediate Dam" is greater than 20 feet in vertical height but equal to or less than both 100 feet and 50,000 acre-feet in capacity, or is greater than 1,000 acre-feet in capacity but equal to or less than both 50,0000 acre-feet in capacity and 100 feet in vertical height.

d. A "Large Dam" is greater than 100 feet in vertical height, or greater than 50,000 acre-feet in capacity.

4. <u>Hazard Classification Report</u>

a. The report shall include floodplain maps showing the inundated areas. In the case of a single reservoir with multiple dams, an analysis of each dam and its downstream channel is required.

b. Include cross-sections showing elevations, location of structures, and channel width at critical sections where development or structures exist. The sections shall show the dam break total discharge, average velocity and the flood stage elevation.

c. Provide a tabulation of the dam break and channel discharge parameters and values used for the final estimated dam break study.

d. The sensitivity study should be summarized in tabular form showing the parameters and the results for each cross-section, and also should show the final study parameters for comparison purposes.

e. The conclusion shall include the recommended hazard classification using the criteria as shown above.

f. Append the final computer output to the report in 8-1/2" x 11" paper format.

g. Provide an appendix listing all computer programs and references used for the study.

h. The computer programs that are used by this office are:

(1) U.S. Army Corps of Engineers "HEC-1 Flood Hydrograph Package" (September 1981, or latest version.) (Requires assuming the dam is overtopping at the spillway elevation with a small base flow causing the failure at the maximum section)

(2) National Weather Service "BREACH - An Erosion

Model for Earthen Dam Failures" program by Dr. D. L. Fread,(January 1985) can be used to evaluate the breach parameters used in the HEC-1 Flood Hydrograph Package.

(3) National Weather Service DAMBRK program by Dr. D. L. Fread provides a dynamic analysis of the flood routing downstream of the dam.

B. HYDROLOGIC DESIGN

1. Design Rainfall: The rainfall event for generating the inflow design flood is based upon the hazard classification and size of the dam. Sources for the rainfall data are the appropriate Hydrometeorological Reports (HMR's) by the National Oceanic and Atmospheric Administration (NOAA) publications, or a site specific rainfall study. Rainfall criteria shown below pertains to the minimum standards required for reservoir dams in Colorado. Exception to the design rainfall standard is a spillway design using an Incremental Damage Analysis.

FIGURE II-1
DESIGN RAINFALL FOR NEW OR ENLARGED DAMS

DAM CLASS/ DAM SIZE\	I	II	III	IV
Large	PMP	.75PMP	100YR	50YR
Intermediate	PMP	.50PMP	100YR	50YR
Small	PMP	.50PMP	100YR	25YR
Minor	.50PMP	100YR	50YR	25YR

FIGURE II-2
DESIGN RAINFALL FOR EVALUATION OR SPILLWAY
ENLARGEMENT ON EXISTING DAMS

DAM CLASS/ DAM SIZE\	I	II	III	IV
Large	.75PMP	.50PMP	100YR	50YR
Intermediate	.75PMP	.50PMP	100YR	50YR
Small	.75PMP	.50PMP	100YR	25YR
Minor	.50PMP	100YR	50YR	25YR

a. For an Incremental Damage Analysis, the design rainfall is that which produces a flood of such a magnitude that the overtopping and failure of the dam does not cause a significant increase in property damage and an increase in loss of life over that which would occur during the design rainfall flood had the dam not been built. See the Section on Incremental Damage Analysis in PART II.B.3 in this guide for details.

b. Site specific rainfall data or hydrometeorologic analysis is determined by following the procedures used by the National Weather Service or as outlined in the United States Bureau of Reclamation (USBR) Flood Hydrology Manual (1989), Chapter 3.

c. When using stream gaging stations and rainfall gage data for determining base data for inflow design floods having a frequency equivalent to or more frequent than the 100 year event, the analysis procedure will be subject to the State Engineer's approval, or the calculation shall be based on procedures outlined in the publication:

> "United States Water Resources Council, Guidelines for Determining Flood Flow Frequencies, Bulletin # 17B of the Hydrology Subcommittee, Revised Edition, Interagency Advisory Committee on Water Data, U.S. Department of the Interior, Geological Survey, Office of Water Data Coordination, Reston, Virginia, 22092, March, 1982"

d. Design Rainfall or Precipitation values are found in the United States Department of Commerce, National Oceanic and Atmospheric Administration (NOAA)- National Weather Service publications.

(1) Probable Maximum Precipitation (PMP) values for Colorado may be determined from the following sources:

(a) Hydrometeorological Report No. 51 - "Probable Maximum Precipitation Estimates, United States East of the 105th Meridian." (HMR-51) and Hydrometeorological Report No. 52 - "Application of Probable Maximum Precipitation Estimates- United State East of the 105th Meridian" (HMR-52)

(b) Hydrometeorological Report No. 49 - "Probable Maximum Precipitation, Colorado and Great Drainages." (HMR-49) This area is west of the Continental Divide.

(c) Hydrometeorological Report No. 55A - "Probable Maximum Precipitation Estimates, United States Between the Continental Divide and the 103rd Meridian." (HMR-55A)

(2) For 100, 50, or 25 year design storms the NOAA

Atlas No. 2; "Precipitation-Frequency Atlas of the Western United States, Vol III - Colorado" (NOAA-2) is generally used in lieu of site specific statistical studies.

e. The State Engineer uses the U. S. Army Corps of Engineers computer model HEC-1 for evaluating the Inflow Design Flood. The synthetic storm data that is entered into the HEC-1 computer program is determined from the "Depth-Duration Values" table as shown below. The data is entered on the "PH Record" or Hypothetical Storm Record.

FIGURE II-3

PRECIPITATION DEPTH-DURATION VALUES FOR HEC-1 "PH" RECORD

Source	Storm	5 min	15 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	48 hr
HMR-55A	GS	A	A	x	I	I	x	I	x	I
HMR-55A	LS	B	x	x	x	x	x	N	N	N
HMR-49	GS	*	*	C	C	C	x	x	x	x
HMR-49	LS	B	x	x	x	x	x	N	N	N
HMR-51/52	GS	x	x	x	I	I	I	x	x	x
NOAA-2	ALL	x	x	x	x	x	x	x	x	N

<u>NOTES: For FIGURE II-3 "Precipitation Depth-Durations Values for HEC-1 "PH" Record.</u>

By using the matrix in the above table and the index below a smooth depth-duration curve may be developed for the storm of interest.

GS: General Storm
LS: Local Storm
x : Precipitation value for this duration can be determined directly from the source publication.
N : Duration of storm not applicable to this series
I : Precipitation value is readily interpolated from a plotted depth-duration curve
A : Precipitation values for these durations computed by : 15 min = 45% of 1 hr; 5 min = 38% of 15 min
B : Precipitation value for this duration is computed by : 5 min = 45% of 15 min
C : Precipitation values for these durations computed by : 1 hr = 25% 6 hr; 2 hr = 48% 6 hr; 3 hr = 66% 6 hr.
* : No current recommendation; HMR-49 Local Storm is more critical for short duration precipitation.

2. Inflow Design Flood Parameters: The inflow design flood is based upon the probable future flow of water and is based on reasonable hydrologic and geologic factors. For the purpose of the State Engineer's review, the dimensionless unit hydrograph technique will be used to evaluate hydrology studies and evaluate the adequacy of existing or proposed spillways. The United States Bureau of Reclamation Flood Hydrology Manual is the adopted reference. Chapter 4 outlines the procedure. In addition the 1987, Third Edition of the USBR Design of Small Dams, Chapter 3, has a brief discussion of the same procedure. The State Engineer will accept other hydrological methods provided similar inflow design flood magnitudes, time to peak, and volumes are obtained. Parameters used in the procedure are developed as follows:

a. Evaluate the watershed basin parameters using both a map and a field reconnaissance considering the following:

(1) The size of the drainage basin or each sub-basin should not exceed 500 square miles. Sub-basins with significantly different characteristics with respect to the others should be evaluated separately.

(2) Identify the length of the longest water course and the characteristics of the channel roughness during the flooding conditions for each basin or sub-basin. Specific attention should be made to over bank flow retarding vegetation, and overland flow for floods equal to or greater than the flood event being evaluated.

(3) Determine the end point elevations for each basin or sub-basin water course identified above.

(4) Determine soil permeability or infiltration properties of the various portions the basins using the four general SCS types noting the vegetal cover and current land use. Identify location and proximity of facilities where people live, work or play that may be within the floodplain.

b. The State Engineer has chosen the Army Corps of Engineers HEC-1 computer program for making an independent evaluation of the Inflow Design Flood. The following discussion includes the HEC-1 options and input modifications used by the State Engineer.

(1) Drainage areas greater than 500 square miles should be split into smaller basins. Major stems of the stream system which differ significantly in

shape, steepness, geology or land use/vegetative cover should also be analyzed separately and then combined. When combining several hydrographs with the HEC-1 program using the USBR unit hydrographs it will be found that the unit of time between hydrograph ordinates can be different for each basin. To properly combine each basin, the ordinate time increments must be the same. It is suggested to use the unit hydrograph time increment for the largest subbasin for each of the smaller subbasins.

(2) In cases where the reservoir area is large in relation to the full basin area, an analysis of the reservoir as a separate subbasin can produce a lower peak runoff because the intense portion of the design rainfall will generally occur and route out of the reservoir before the basin peak can arrive.

(3) The rainfall distribution for all design storms is the "Balanced Storm" or a triangular precipitation distribution as generated by the HEC-1 "PH" input record. We do not recommend using the rainfall distribution arrangement as shown in Figure 3-9 of the USBR Flood Hydrology Manual. By using the "PH" record input for the HEC-1 precipitation, the "Balanced Storm" will be automatically developed. The PH record variable "TRSDA" (Storm Drainage Area) must be assigned the value of ".01" because the rainfall areal reductions should have been made using the appropriate HMR or NOAA Atlas procedures.

(4) The State Engineer has adopted the USBR Flood Hydrology Manual definition for lag time (or "Lg") as the time from the center of the unit rainfall excess to the time that 50 percent of the volume of the unit runoff has passed the concentration point or the point of interest.

(5) Selection of the appropriate Unit Hydrograph and Lag Time from Chapter 4 of the USBR Flood Hydrology Manual, should be based on the geographical characteristics of the area. For example, some mesa-like areas which are found in the "Rocky Mountains" hydrographic region are most likely to have a hydrologic response equivalent to the hydrographic region "Southwest Desert, Great Basin and Colorado Plateau." In addition, a drainage basin completely within the San Luis

Valley lowlands would be expected to have a hydrologic response equivalent to the "Great Plains" hydrographic region. It is also expected the basin hydrologic response data for study basins primarily below 7,000 feet and east of the Front Range, to be determined from the "Great Plains" hydrographic region. For the area west of this line, the hydrologic response data would be determined from the "Rocky Mountains" hydrographic region according to the appropriate storm type. For highly developed urbanized areas, use the hydrologic data for urban basins.

(6) Tables 4-1, 4-2, and 4-3 in the USBR Flood Hydrology Manual are the study results of several drainage basins with various parameters which show the reconstructed Ct and Kn values for different river drainages. A thorough understanding of Section 4.1(e) of the USBR Flood Hydrology Manual will be essential during this step. A sensitivity analysis of the lag is recommended because changes in the Kn values can make major differences in the final hydrograph peaks. The following unpublished table, although different from the USBR Flood Hydrology Manual, shows some general basin descriptions with corresponding Ct and Kn values developed through reconstruction by the USBR during their PMF Study of the Arkansas River above the Pueblo Dam.

FIGURE II-4
ARKANSAS RIVER LAG COEFFICIENTS (USBR)

GROUND COVER	CT	Kn
Above Timberline/ Tundra Outcrop	1.0	.0385
Snow Covered Area	4.8	.1846
Forest Good Cover	3.2	.1231
Range/Pasture/Sage/Grass	2.4	.0923
Rocky Canyons	0.5	.0192

(7) Antecedent Moisture Conditions: For PMF's in large drainage areas subject to snowmelt flooding, the seasonal PMF should be superimposed upon the 100 year snowmelt flood. Chapter 4 of the USBR Flood Hydrograph Manual provides an excellent discussion on this topic.

(8) Initial Abstractions and Infiltration: Given

that pre-wetting or antecedent moisture conditions can prevail, studies should assume no initial abstractions and then use the minimum infiltration loss rates throughout the duration of the PMP. In cases of depression areas or highly vegetated areas, an Initial Abstraction may be considered. Minimum infiltration rates are based on the four SCS soil groups and may be estimated using the USBR Flood Hydrology Manual , Chapter 4, page 112.

(9) Starting water levels for flood routing. Exceptions to the criteria presented below will be allowed by the State Engineer for good cause shown.

(a) For the snowmelt component of the inflow design flood, begin the reservoir and spillway stage at the snowmelt flood discharge rate.

(b) For rainfall inflow design floods, begin the reservoir spillway stage at the elevation of the emergency spillway crest.

(c) Flood control dams may be started at the first uncontrolled service spillway.

3. Incremental Damage Analysis: The concept of Incremental Damage Analysis (IDA) is based on the idea that there are reservoir dams so small in capacity in relation to the drainage basin that a dam failure caused by an overtopping inflow flood is insignificant in relation to the damage that would be caused by the same inflow flood had the dam not been built. Conceptually, this can reduce the required spillway capacity and therefor the cost of construction. The following criteria and procedures outline the requirements and justification for an IDA spillway.

a. An IDA shall be based upon a comparison of two floods: First, a base flow flood of a such a magnitude that will just cause a dam failure by overtopping, routing the flood downstream assuming "no dam" is in place and second, the "overtopping dam failure" flood due to the base flow flood. The area between the compared flood stage elevations is known as the incremental zone. A spillway capacity that passes the base flow flood will be acceptable where it can be shown that the dam failure flood would not cause additional loss of life and would not cause significant incremental damage downstream. Design freeboard requirements will still apply.

b. For comparison of the two floods, no additional loss of life or "significant" incremental damage is expected if the incremental increase in depth of flow is two feet or less and the product of (1) the average floodplain flow velocity (in feet per second) and (2) the incremental depth of flood (in feet) is less than seven within the incremental zone.

c. The IDA must continue far enough downstream of the dam to assure the study is conclusive. The study shall include intermediate cross sections where critical areas and structures exist, and where channel transitions affect the depth and velocity of the flow.

d. There are three computer dam break programs currently used by the State Engineer for evaluating an IDA. These are: 1) The HEC-1 Flood Hydrograph Package by the US Army Corps of Engineers, 2) The National Weather Service "DAMBRK" by Dr. D. L. Fread, and 3) The National Weather Service "BREACH" by Dr. D. L. Fread. Our use of these methods does not preclude the use of other methods or programs. However, the other methods will be expected to produce similar results.

e. Documentation of the incremental damage analysis shall include but not be limited to: Topographic maps of the affected areas, cross-sections and profile of the downstream channel showing the flood stages for "overtopping dam failure" and "base flow" (no dam). Include the velocities and discharges for each flood stage. Documentation shall include the computer printouts showing flood discharges, stage, and velocities, with respect to time.

4. Hydrology Report: The hydrology study shall be based upon accepted engineering practice and the report shall include sufficient detailed information so that the reviewer may reproduce the results of the study. The following information shall be included.

a. Location of proposed dam by quarter section, section, township, range, and principle meridian; and the bearing and distance from Station 0+00 point on the dam, to a section corner. The distance and bearing need not be a field survey but the dam should be easy to locate accurately on a 1:24,000 scale map.

b. Basin description shall include: The name of stream impounded or indicate the dam is off stream and name the tributary or drainage basin; elevation of the dam crest and range of the basin elevation in accordance with U.S.

Coast and Geodetic Survey (USCGS) elevation; discuss the basin development, drainage network, geological setting, soils, and vegetative cover; and discuss future growth potential based on the most authoritative sources available.

c. Topographic map of drainage of area above and below the dam. Indicate the drainage area in square miles.

d. Discuss the development of the unit hydrograph, source of the data and the development of the lag time. If the hydrograph is based on an actual flood event, include a description of the reconstruction study.

e. Discuss the development and source of the rainfall data, distribution of the storm magnitude.

f. Discuss rainfall interception and infiltration losses and loss rates.

g. Summarize the results of the hydrology study, including the peak inflow design flood hydrograph, volume of flood, and the hazard classification. Also provide information concerning the computer program used and a listing of all input data.

h. Include an outlet discharge capacity rating table for each foot of head above the inlet or control section if the hydrology study includes credit for the outlet discharge capacity. Include the equations for determining the discharge rate.

i. Include a spillway discharge capacity rating table for each foot of head above the control section, including the dam crest elevation. Include the equations for determining the discharge rate for the spillway.

j. Include a table showing the reservoir area in (acres) and storage capacity (in acre-feet) for each foot of gage height from zero storage to the crest of the dam. Indicate the maximum elevation of the dead storage level, outlet invert or elevation, and the elevation of the spillway(s). The gage height shall be referenced to the USCGS elevation.

C. GEOTECHNICAL CRITERIA FOR INVESTIGATION AND DESIGN

1. Geotechnical/Geological Reports: A complete geotechnical and geological investigation must be conducted in sufficient detail to support a structural design for all new or enlarged dams. Feasibility level investigations and reports are not acceptable for design purposes. The extent of investigation, testing, and evaluation required varies with the hazard class and size of the dam, however it is desirable to ensure that an adequate level of investigation is done for every dam. The geotechnical report should include an evaluation of the foundation and the materials available for construction. The report should also include a description of the geological structures, faults, tectonism, slide history, mining history and seismic activity as it relates to the site and hazard classification. The report must include a discussion of the design requirements as indicated within this section. The minimum requirements for a geotechnical investigation are outlined below and only applicable portions of these investigation requirements should be used for any work on existing dams.

a. Class I and Class II dams.

(1) Geology - Provide a geological assessment for the following items:

(a) Regional setting.

(b) Local area.

(c) Dam foundation.

(d) Slide potential of reservoir rim.

(e) Areal and regional seismic history and potential as required.

(2) Geotechnical investigation of foundation.

(a) Drilled test holes shall penetrate into bedrock or have a depth of 1.5 times the proposed height of the dam, whichever is less.
(b) Development of complete drilling logs, field data, and collection of laboratory samples, following USBR Design of Small Dams recommendations.
(c) Appropriate Standard penetration tests for all drill holes.

(d) Field soils classification using the Unified Soil Classification System.

(e) Drill hole water level.

(f) In-situ permeability tests as required.

(g) Gradation tests of foundation materials, especially in the vicinity of possible drain systems.

(h) Obtain undisturbed samples for testing.

(i) In-situ density.

(j) Shear strength tests of foundation materials.

(k) Compressibility of foundation materials.

(l) Rock quality of foundation rock.

(m) Presence of dispersive clays or clayey materials that exhibit residual strength properties in the foundation soils.

(n) Undesirable characteristics of foundation rock (e.g., open fractures, presence of soluble salts, low shear strength materials, etc.)

(o) Foundation drill logs developed during the geotechnical investigations shall be shown on a profile of the dam foundation along centerline, both on the plans and in the Geotechnical Report.

(3) For each of the Borrow Materials.

(a) Identify the availability and location of enough borrow material to construct the dam as specified.

(b) Gradation analysis for each class of proposed materials.

(c) Laboratory classification of soils.

(d) Compressibility.

(e) Remodeled permeability, if appropriate.

(f) Shear strength characteristics.

(g) Proctor compaction test curves.

(h) Presence of dispersive clays.

(4) Spillway Site Investigation - Rock.

(a) Geologic description of the rock.

(b) Bedding and jointing characteristics.

(c) Adequacy of site to accommodate proposed spillway.

(5) Spillway Site Investigation - Earth.

(a) Soil Classification.

(b) Soil logs along the channel profile extending at least 5 feet below the bottom of the spillway channel.

(c) Density or bearing capacity of soils.

(d) Gradation of soils.

(6) Geologic and geotechnical earthquake investigations for seismic loading conditions on all Class I dams and all Large and Intermediate Class II dams. (Not required for Small and Minor Class II dams.)

(a) The geologic investigation shall include information on the faults and fault history in the immediate and regional areas which may affect the dam. In addition, the reservoir perimeter must be evaluated for slide potential under earthquake conditions.

(b) Evaluate the liquefaction potential of borrow and foundation soils.

(c) If a deformation analysis is necessary, determine the dynamic shear strength of the foundation and borrow materials.

b. Large, Intermediate, and Small Class III dams.

(1) Geology - Include information on the following:

(a) Local area.

(b) Dam foundation.

(c) Slide potential of reservoir rim.

(2) Geotechnical investigation of foundation.

(a) Drilling to and penetration into bedrock or 1.5 times the height of the dam, whichever is less.

(b) Development of complete drilling logs.

(c) Standard penetration tests.

(d) Field classification of soils.

(3) Geotechnical investigation of borrow materials.

(a) Demonstrate availability of sufficient quantity of specified borrow materials.

(b) Gradation of proposed materials.

(c) Laboratory soil classifications.

(d) Proctor compaction test curves.

(4) Spillway investigation - as listed above for Class I and Class II dams in C.1.a.(4).

c. Minor Class III and all Class IV dams.

(1) Geology - Include information on the following.

(a) Local area.

(b) Dam foundation.

(2) Geotechnical investigation of foundation.

(a) Field soil classifications.

(3) Geotechnical investigation of borrow

materials.

(a) Demonstrate availability of sufficient quantity of specified borrow materials.

(b) Field classification of soils.

2. Static Stability: The slopes must be stable under all conditions of operation. For dams up to 50 feet high, the methods and procedures for determining slopes outlined in the United States Bureau of Reclamation publication Design of Small Dams, 2nd Edition and newer editions are acceptable. For dams over 50 feet in height, static stability analyses using an acceptable computational method commonly used in the industry shall be performed to establish slopes that meet the following design criteria:

a. The minimum factor of safety under high normal water level steady state seepage conditions is 1.5.

b. The minimum factor of safety for rapid drawdown conditions is 1.2. Various water levels and steady state piezometric surfaces should be considered.

c. The minimum factor of safety after construction should be 1.25 for both upstream and downstream slopes.

d. Shear strength parameters should normally be based on consolidated undrained triaxial shear tests with pore pressure measurements as required.

e. Both effective stress and total stress analysis are satisfactory.

f. For those dams which require consideration of residual shear strength of foundation materials, the minimum factor of safety using residual strength parameters may be less than those described above. The State Engineer shall determine the minimum allowable safety factor.

3. Seismic Stability: Seismic stability analysis is required for all New and Enlarged Class I dams of any size, and for all New and Enlarged, Intermediate or Large size Class II dams.

a. Dams requiring seismic analysis shall be designed to withstand at least the predicted earthquake loads with a full reservoir under steady state seepage conditions. Predicted earthquake loads shall be based on an analysis of active or potentially active faults which may affect the dam, and on general considerations of seismicity in the associated seismotechtonic province (Reference Colorado Geological Survey, Bulletin 43 by

Kirkham and Rogers.) Detailed field investigations indicating fault inactivity may be used to supplant classification as a "potentially active fault". The predicted ground motions at the dam site shall be determined from fault rupture and energy attenuation relationships acceptable to the State Engineer.

b. For dams requiring seismic stability analysis, the minimum analysis required is a pseudo-static analysis utilizing an appropriately selected load coefficient of no less than 0.05. Larger load coefficients or a more rigorous analysis may be required, as discussed below.

c. Dams which require seismic analysis, and which have cohesionless materials in the embankment or foundation, shall be evaluated for liquefaction potential. The evaluation will generally consider, as a minimum screening process, the anticipated earthquake magnitude versus estimated epicentral distance of movement on the causative fault. In general, the results of standard penetration tests (SPT) shall be considered and evaluated versus seismic loading to evaluate liquefaction susceptibility. Other analysis techniques may also be employed as necessary or advisable. If the evaluation indicates that the material in question may be liquefiable under the design earthquake loading, the potential for liquefaction shall be eliminated, or the design shall incorporate systems to limit the effects of liquefaction to prevent excessive deformation and dam failure.

d. For dams which require seismic analysis, a pseudo-static analysis is sufficient if all of the following conditions are satisfied:

(1) The dam and foundation materials are not subject to liquefaction.

(2) The dam is a well built (densely compacted) structure and predicted peak bedrock accelerations at the dam site are 0.2g or less, or the dam is constructed of clay on a clay or rock foundation and the predicted peak bedrock accelerations are 0.35g or less.

(3) The static stability analysis safety factors, for critical failure surfaces involving the dam crest (other than for the infinite slope case) are greater than 1.5.

(4) Freeboard is a minimum of 3% of the embankment height, but no less than 3 feet.

e. If pseudo-static analysis is used, the minimum acceptable factor of safety obtained by this method is 1.0. The pseudo-static load coefficient used shall be at least one-half of the predicted peak bedrock acceleration (g's), and not less than 0.05.

f. Where pseudo-static analysis is not appropriate, a deformation analysis, using techniques and methodologies which are generally used in practice and are acceptable to the State Engineer, shall be performed. The freeboard remaining following the predicted deformation of the dam shall not be less than 3 feet, nor shall deformation be so excessive that failure of the dam by internal erosion is likely.

g. Defensive design measures shall be incorporated in dams subject to earthquake loading, such as extra freeboard, wider than normal core zones, filters, drains, and zoning located to reduce embankment saturation.

4. Design Criteria:

a. The embankment must be safe against failure due to overtopping by providing adequate freeboard or have a hardened surface that resists erosion.

b. The embankment must not over stress the foundation.

(1) Design and treatment of the foundation is dependent upon the type of dam being designed and insitu materials within the foundation. With little control over the insitu materials the weak points of a dam are generally within the foundation. Several methods for treating and stabilizing the foundation are available and each is used to address a specific foundation weakness. The USBR Design of Small Dams discusses the treatment of rock, pervious and impervious soil foundations, cutoff trenches and installation of grout curtains and slurry trench cutoffs. In addition, it discusses the control of seepage during construction and for final design.

(2) Several books have been written concerning only the subject of foundation design and treatment. Appropriate foundation design will be evaluated on a case by case basis.

c. Appurtenant structures must be designed and constructed to not jeopardize the safety of the dam.

d. Minimum compacted densities for embankment materials with a significant content of fine grained materials shall be 95 percent of maximum dry density as determined by ASTM D-698 (Standard Proctor) or 90 percent of maximum dry density as determined by ASTM D-1557 (Modified Proctor). Impervious zones with cohesive materials shall be controlled using the Standard Proctor criteria to maintain the plastic nature of the material.

e. The minimum density for cohesionless materials placed within an embankment shall be 70 percent relative density, as determined by ASTM D-4253 and ASTM D-4254.

f. Minimum Freeboard Requirements.

(1) New Dams and Enlargements, the largest of:

(a) Maximum height which will prevent overtopping by wave action; or

(b) Inflow Design Flood maximum water surface plus one foot of residual freeboard; or
(c) A minimum of 5 feet

(2) Existing Dams, the largest of:

(a) Maximum height which will prevent overtopping by wave action; or

(b) Maximum height required to pass the Inflow Design without overtopping; or

(c) A minimum of 3 feet.

h. Camber of the dam crest above the nominal design elevation shall be provided, based on considerations of dam height and material compressibility, in order to maintain freeboard. The maximum camber generally ranges between 2 to 4 percent of the maximum dam height.
i. Crest width shall be equal to H/5 + 10 feet, where H = maximum vertical height of the dam. However, the minimum crest width shall not be less than 12 feet. The maximum crest width required is limited to 25 feet.

j. Filter and Drain Design - Seepage through the embankment, abutments, foundation, and under and around appurtenances shall be controlled to prevent internal erosion and external sloughing. Drain capacity should be sized to carry seepage flows several times more than the predicted maximum.

(1) Chimney drains, filter and drainage blankets, toe drains, and relief wells should be located where the drainage is most effective according to the most recent literature.

(2) Granular filters and drains must be appropriately graded to prevent migration of particles from the base soil into the filter/drain, and to provide sufficient permeability for ready removal of seepage from the base soil. Design of granular filters and drains should conform to SCS Soil Mechanics Note No. 1, 1986, or U.S.Bureau of Reclamation Design of Small Dams 3rd Edition, unless deviations are substantiated by approved laboratory tests. The procedure and results of which are subject to review and approval.

(3) Granular filters and drains shall have a minimum thickness of 12 inches. Where the maximum particle size of the filter/drain materials exceeds one inch, the filter/drain thickness shall be increased at the rate of one foot of filter/drain per inch of increase in maximum particle size. The maximum particle size shall not exceed 3 inches.

(4) Concrete sand meeting the gradation requirements of ASTM C-33 may be used as a filter for all fine-grained base soils as defined by the Unified Soils Classification System.

(5) Sand filters and drains shall not contain an excess of 4 percent of the material by weight passing the #200 sieve size. This will assure sufficient drain permeability.

(6) Granular filters must be constructed of hard, durable mineral particles, which are not subject to excessive breakdown under repeated cycles of wetting and drying.

(7) Perforated or slotted drain pipes may be used to collect and remove seepage from granular filters and drains. Underdrains and collection pipes must be constructed of non-corrosive materials. Slots and perforations shall be sized according to SCS Soil Mechanics Note No. 1, 1986 or the U.S.Bureau of Reclamation Design of Small Dams 3rd Edition. Sufficient open area of perforations or slots shall be provided to handle anticipated seepage rates

with minimal head loss across the opening.

(8) Granular envelopes around perforated or slotted drain pipe must have a minimum dimension of 6 inches of drain material around the outside of the pipe. The maximum particle size shall not exceed 1/2 inch unless the envelope thickness is increased at the rate of one foot per inch of maximum particle size.

(9) Geotextiles shall not be used as filters in an area where they are not readily accessible and replaceable in a safe manner. In areas where geotextiles may be used, their design must conform to the current industry state-of-the-art with respect to material properties, filtering ability, permeability, and clogging criteria. An available reference is SCS Technical Note No. 30, 1990.

k. Slope Protection - The embankment and groins must be protected against external erosion.

(1) Rock riprap shall be well graded, durable, and adequately sized to withstand anticipated wave action. Wave analysis shall be based on factors such as wind velocity, wind direction, fetch, and slope angle.

(a) Wave characteristics may be determined from references such as:

Corps of Engineers, Engineering Technical Letter ETL 1110-2-221, "Wave Runup and Wind Setup on Reservoir Embankments," Nov., 1976, or

U.S. Bureau of Reclamation ACER Technical Memorandum No. 2 "Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams" December 1981., or

U.S. Soil Conservation Service, Engineering Technical Release No. 69, May 24, 1983.

(b) Riprap stone and size and required layer thickness may be determined from references such as:

Earth and Earth-Rock Dams by Sherard, et.al., 1963, or

U.S. Soil Conservation Service, Engineering Technical Release No. 69, May 24, 1983.

(c) In general, maximum rock size shall be about 1.5 times the average rock size, and the layer thickness shall be equal to or slightly larger than the maximum rock size. Among other references, standard gradations and bedding thickness for different average rock sizes may be obtained from U.S. Soil Conservation Service, Technical Release No. 69, May 24, 1983.

(2) Riprap must be placed on a well-graded, pervious sand and gravel bedding. Use of geotextile fabric directly beneath the riprap is not recommended, due to puncture and tearing problems. However, the geotextile fabric may be used under a suitable bedding which protects the fabric during installation. Riprap bedding should consist primarily of gravel, ranging from coarse sand to coarse gravel. Bedding should not include fine sand or more than 4% minus 200 sieve.

(3) Alternative methods of upstream slope protection may be used where warranted or desirable, and when properly designed and constructed. Soil cement shall conform to the design and construction criteria of the Portland Cement Association. Other proposed means of upstream slope protection will be evaluated on a case-by-case basis.

(4) Downstream slopes and groins shall be protected from erosion caused by surface runoff. Downstream slope protection usually consists of seeding native grasses into a topsoil placed on the slope, although alternative methods, such as erosion blankets or armoring with rock, may be used.

l. The dam crest shall be accessible by equipment and vehicles for emergency operations and maintenance. A wearing surface, such as road base material or asphalt shall be provided to prevent rutting of the crest.

5. Concrete Dams: The design of Concrete, Roller Compacted Concrete or Soil Cement dams are not discussed in this guide at this time. It is suggested the design engineer seek current references on the subject.

D. SPILLWAY DESIGN CONSIDERATIONS: Spillways are the safety relief valves for reservoir dams. They should be capable of passing and withstanding the sustained forces of the inflow design flood without causing unacceptable damage.

1. General Polices

a. Over-the-embankment spillways are discouraged for new construction because of settlement problems, however they will be considered on a case by case basis when a spillway cannot be reasonably built elsewhere.

b. Pipe or conduit spillways, which serve as the only spillway for the dam, are discouraged unless the design storm can be completely retained within the reservoir and the ungated pipe should be able to drawdown the reservoir water surface level enough within seven days to safely store a 100-year storm. The minimum sized pipe or conduit should not be less than 30 inches. Exceptions will be considered on a case by case basis.

c. Spillway Right-Of-Way: The owner must either own or have an easement for the spillway channel down to the natural channel including the stilling basin. In cases where the spillway discharges into an adjacent drainage basin thereby increasing the natural flow, the dam owner must own or possess a Right-Of-Way easement in the flood channel downstream to the location where the maximum discharge would no longer create additional significant damage.

2. Design Considerations:

a. The design of the spillway and channel protection shall be based on the duration and volume of the frequent flows. Earth spillways shall be protected from frequent flow by a service spillway that carries the majority of reservoir inflows.

b. The reservoir and dam shall be safe during all ranges of spillway operation flow.

c. Spillways subject to snow and ice conditions shall be evaluated for blockage during the spring. Placing the spillway on the sunny side of the reservoir or minimizing snow drift development can help mitigate the problem. Potential for weathering of the approach channel, chute and energy dissipation system should be considered and appropriate protection provided.

d. Spillway flow control should be stable at a fixed location and should not become submerged by downstream conditions during any discharge. In addition, the shape of the weir should be designed to prevent excessive negative pressures on the downstream face of the weir.

e. All spillway channels not protected by concrete lining or in sound rock shall have concrete erosion control beams across the channel. An analysis of "bulk length" as developed by the U.S. Soil Conservation Service in TR-052 "A Guide for Design an Layout of Earth Emergency Spillways as Part of Emergency Spillways Systems for Earth Dams" shall be used to justify the unprotected spillway design.

f. Channels shall be designed to either eliminate standing or cross-wave problems or have sufficient freeboard to contain the flow. Usual freeboard is 3 to 6 feet above the maximum expected discharge water surface.

h. For extreme concrete channel velocities approaching 100 feet per second, special designs to mitigate channel cavitation are required.

i. Log booms shall be installed where logs and other debris may block spillway flow or damage spillway structures.

3. Terminal Structures: Generally, the increased flow velocities for spillways must be dissipated. The decision whether to dissipate the spillway energy for the maximum discharge is a financial one. Below are listed some guidance when considering full capacity protection:

a. The spillway and channel must be located away from the dam and terminate far enough downstream to prevent erosion of the dam and appurtenances. The natural channel below the spillway should not experience significant damage beyond that which would occur had the dam not been built.

b. While energy dissipators do not need to be designed to control 100 percent of the maximum discharge, the structures and dam must be capable of withstanding the forces from the full spillway discharge capacity.

4. Fuse plugs and "Hydroplus Systems" (Trade Mark): Erodible section or dump type spillways shall be designed using Incremental Damage Analysis criteria outlined in Section II-B-3 above.

E. OUTLET DESIGN CONSIDERATIONS:

1. Outlet capacity requirements:

a. Emergency release requirements for all Class I dams is based on lowering the water surface elevation 5 feet in 5 days beginning at the high water line. Other Class of dams shall be designed using the same criteria.

b. Outlets shall be capable of passing inflow to the reservoir with a minimum of ten feet of head, in order to meet the demands of downstream senior water rights, and shall include the owner's reservoir release requirements. It is recommended that the reservoir inflow rate should be at least the mean annual peak flow. The State Division Engineer has final approval of the required administrative outlet capacity.

2. Outlet Design considerations:

a. Outlet size and capacity could be controlled by the need to by-pass the stream flow during construction. This option should not be overlooked in the design and planning phase.

b. Outlets are costly structures and are often difficult and very expensive to replace or repair. Design capacities, equipment and materials should be carefully considered to attain the longest life possible.

c. Outlets shall have trash racks unless excepted by the State Engineer for good cause shown.

(1) For trash racks that are not accessible for cleaning, the maximum velocity through the rack should be limited to 2 feet per second. If the rack is accessible for cleaning the velocity may approach 5 feet per second however vibrations may become a problem.

(2) Trash racks shall be structurally designed for a loading condition of 25 percent of the maximum reservoir head.

(3) Trash racks may be eliminated when the basin is free from trees and other heavy brush that may cause clogging of the outlet system. Trash racks shall be required when the reservoir becomes accessible to the public.

d. Except for ungated outlets on flood control dams, all new dams shall have operating, guard gates, or bulkhead provisions installed at the upstream end of the conduit. Outlet intakes that are being replaced shall include new guard gate systems designed and installed.

e. All principal outlets that are tied to transmission pipelines shall have a by-pass or blowoff valve that will meet the outlet capacity requirements discussed in E.1 above.

f. All outlets shall have energy dissipators, plunge basins, or have adequate riprap to prevent undesirable erosion of the surrounding structures.

g. When pipe velocities exceed 50 feet per second, special attention shall be given to cavitation.

h. Air venting of the outlet should be considered to prevent vibrations caused by surging and for mitigation of cavitation.

i. Outlet conduits shall have anti-piping control systems. This may include anti-seep (cut-off) collars, Soil Conservation Service sand collars, or installation of a filter envelope along the downstream portion of the outlet pipe.

j. Outlet systems that use hydraulic controls shall have multiple backup lines or systems to ensure they will be operable. Hydraulic lines should be installed in buried or encased conduits to allow easy replacement and minimize potential for damage.

k. For outlet gates and equipment that operate by electricity, accessible standby generators must be available and periodically tested.

l. All pressure flow pipes within dams must be shop tested by the manufacturer at a hydrostatic pressure equivalent to 1 1/2 times the operating pressure. After installation, the pipe and joints shall be tested for leakage. The leakage test procedure should meet the American Water Works Association standard for the design pressure.

F. RESERVOIR AND AREA

1. Seepage: Leakage through the reservoir abutments and downstream channel may be detrimental to the valley wall stability. In some cases, the leakage may be desirable as a contribution to minimum stream flows, or it may provide ground water recharge for other important works. In any case, the effects of reservoir leakage need to be thoroughly investigated and the adverse effects mitigated.

2. Reservoir Slides: Local soil and rock mass stability must be evaluated to assure that the reservoir water levels do not cause the mass to become unstable.

   a. Reservoir perimeter slides may be caused by lubrication or lowering internal strength characteristics of the soil mass by the rapid rise and lowering of the water level in the reservoir, or by wave erosion undercutting banks and slopes. Consequences of a landmass slide could be:

      (1) Sudden release of a large soil and rock mass into the reservoir basin causing large waves that could overtop and breach the dam.

      (2) Slow sliding masses that will reduce the reservoir capacity causing overtopping, or possibly plugging or inundating the outlet works. When sliding is directed onto the dam itself deformation and cracking of the dam and structures may occur.

   b. Leakage into the reservoir basin and rim may activate local faults and increase the frequency and magnitude of seismic activity.

3. Reservoir Site Cleaning: The reservoir basin shall be cleared of loose logs and debris to minimize the effects on the trashracks and spillway during first filling.

4. Reservoir Rights-of-Way: The design of reservoir dams or enlargements must assure that private property, exclusive of marina type structures within the flood stage zone, is not damaged during flooding. This may be accomplished by either direct ownership or ownership of a floodway easement.

5. Accessibility to Dam: The dam crest and appurtenant structures shall be accessible by equipment and vehicles during an emergency. Spillways and outlets especially shall be accessible, and wherever possible, alternate access routes should be provided.

G. WATER DIVERSION CONTROL PLANS: The responsibility for diversion and control of the stream or river during construction is generally the responsibility of the contractor. However the design engineer usually provides information concerning the frequency of stream flow levels and often proposes a control plan for consideration. Because the coffer dam is generally included in the dam embankment the design engineer and the State Engineer have an interest in the construction and design of the diversion structure. Under Rule 9.A.(3) the State Engineer must approve the diversion control plan.

1. Diversion and Control: Diversion and control of a stream or river is a high risk operation if a coffer dam is required. Factors to consider in the design include:

a. Risk of failure to the lives of workers and residents downstream.

b. Length of time the risk will exist.

c. Cost of equipment down time while the flood passes, cost of clean up, and the cost of reconstruction.

2. Design Considerations: The diversion structure shall be designed for a minimum of a 25-year flood event if failure is expected to cause loss of life. The design engineer shall provide recommended procedures for diversion and control of the stream if the diversion structure is to be incorporated in the dam. In any case, the design documents shall contain information concerning the magnitude and frequency of predicted floods during construction.

3. Approval of Plan: The contractor's flood protection plan for Class I and Class II dams shall be prepared by professional engineer and approved by the State Engineer prior to beginning the construction for diversion.

H. INSTRUMENTATION PLAN

1. Purpose: Instrumentation devices are used to monitor the performance of a dam over time. Accordingly, the State Engineer requires a plan for instrumentation and schedules for the periodic measurement, evaluation, and reporting of a dams performance. A recommended reference for the design and measurement of instrumentation is Chapter 12 of the Colorado Dam Safety Manual, 1983 or Geotechnical Instrumentation of Monitoring Field Performance, John Dunnicliff, Wiley-Interscience Publication, 1988.

2. Required Instrumentation: Planning for instrumentation requires a knowledge of the design and predicted behavior of the dam and an estimate of the precision required for each device to be installed. Special instrumentation or additional requirements will be directed on a case by case basis and would only be required in situations where unusual conditions exist. The following tables show the minimum instrumentation normally required for the various classifications of dams for both new/enlarged dams and existing dams:

FIGURE II-6
INSTRUMENTATION REQUIREMENTS
FOR NEW AND ENLARGED DAMS

Instrumentation	Class I	Class II	Class III	Class IV
Surface Movement Monuments	X	X	X	
Seepage Measurement Weirs	X	X	X	
Gage Rods	X	X	X	X
Piezometers	X	X		
100 Foot Station Markers	X	X		
Stream Measuring Flumes	As Required by the State Engineer			

FIGURE II-7
INSTRUMENTATION REQUIREMENTS
FOR EXISTING DAMS

Instrumentation	Class I	Class II	Class III	Class IV
Surface Movement Monuments	X			
Seepage Measurement Weirs	X	X	X	
Gage Rods	X	X	X	X
Piezometers	As Required by the State Engineer			
100 Foot Station Markers	As Required by the State Engineer			
Stream Measuring Flumes	As Required by the State Engineer			

3. Design Criteria: Instruments shall be designed to be

long lasting, or easily replaceable so that little or no correlation between old and new data is required. The following minimum standards are required by the State Engineer:

a. Surface movement monuments must be permanent and be periodically monitored by precise survey instruments. To prevent disturbance by surface impacts, frost action, or vandalism, it is strongly recommended that the upper portion of the monument be encased in a larger steel or concrete pipe. Location of monuments should be at the maximum section and spaced at such intervals such that the performance of the dam can be measured. The design engineer shall recommend monument locations based upon dam design, foundation conditions, potential of abutment slide areas and other locations that warrant observation.

b. Drainage or seepage measurement weirs shall be permanent and installed to prevent water from flowing around or under the weir. The weirs shall be constructed to meet appropriate standards for measurement devices similar to those defined in the USBR Water Measurement Manual. Deviations from standards will require calibration and acceptance by the State Engineer. It is intended that the weir approach basins be designed to allow visual inspection of the water flowing from the source in order to detect whether soil particles are carried in the discharge.

c. Gage rods shall be installed in the proximity of the outlet on all dams. The zero mark of the gage shall be established as the invert elevation of the entrance to the lowest outlet. The gage shall be clearly marked in feet and tenths of feet and extend to within one foot of the dam crest. If the Division Engineer requires, the gage shall be marked in hundredths of a foot. Gage rods shall be correlated with the reservoir storage capacity table and the USGS datum.

d. Piezometers are devices for measuring the hydrostatic pressure within a dam. Measurement of the water level in a piezometer is generally performed by an electric sounding device such as an "M" Scope or a dipping tape. The depth to or elevation of the water surface may be made by measuring the pressure head at an isolated point in the foundation or by measuring the integrated or average pressure up through the embankment. Most dams have open standpipe or observation wells that measure the average pressure in the embankment. These well systems are more durable than other types of piezometers, but they respond very slowly to changes in the water level within the impervious section of the dam. The top few feet of each piezometer should be in a strong encasement to prevent equipment damage or destruction by vandals.

e. Station markers shall be installed along the crest of the dam away from the vehicle traffic lanes. These markers will allow quick location of a problem area that can be related to construction drawing records on file. This information can play an important role in quickly developing remedial actions to prevent the failure of the dam. In addition, the location of maintenance items can be easily dispatched to a work crew.

I. MONITORING PLANS: Once the instrumentation is designed a monitoring plan must be developed. It shall include the frequency of monitoring, who is responsible for collecting and reporting measurements, and provide for the plotting and interpretation of the results.

1. Purpose: There are three major reasons to monitor the performance of dams and their foundations. They are:

1) To observe the performance of the dam in order to detect abnormal changes early enough to prevent failure;

2) To determine if the dam is performing as designed; and

3) To improve scientific knowledge of dam performance in general.

2. Frequency of Measurements: Once instruments are installed at a dam, they need to be systematically measured according to an established schedule and as soon as possible after an unusual events such as an earthquake, heavy flooding, or when unforeseen conditions develop. The schedule should be based on the loading conditions and operation schedule of the reservoir. There are three basic plans that must be developed.

a. First Filling Plan: The objective of the First Filling Plan is to provide a close observation and instrument monitoring schedule while the reservoir level is rising for the first time. The first filling rate should be slow enough to allow the dam to adjust to the new load and seepage forces. Some dams may require each successive reservoir water level held steady for a week or two before filling to the next increment. Others may be large enough that the filling rate is normally slow. The plan is the responsibility of the design engineer, subject to approval of the State Engineer.

b. First Five-Year Plan: The objectives of an after construction or first five-year instrumentation monitoring plan include the following:

(1) Establish baseline historical performance such as drain discharge rates as a function of reservoir gage height and embankment response time.

(2) Establish baseline historical performance for piezometer response versus reservoir gage height.
(3) Evaluate embankment settlement of consolidation rate after construction versus time.

(4) To determine if the dam is performing as designed.

c. Long Term monitoring Plans: The long term plan shall be based on the normal operating schedule of the dam. The time schedule for reading instruments should include the times when the reservoir is at its lowest and at its maximum storage. Embankment movement monuments are to be read once a year for 5 years then the interval may be changed to every 5 years provided no significant movement occurs.

d. In addition, when reservoirs are over 50% full all Class I and Class II dams must be monitored at least twice a month and Class III dams must be monitored at least once every three months. These periodic observations should include reading the reservoir gage level and the drainage weirs as a minimum. These readings must be compared with previous data to detect any emerging or developing problems with the dam.

3. Recording and Reporting Instrument Readings: The design engineer should develop a system for and train the owners personnel in the proper measurement of the instruments, recording and reducing the data into a usable form.

a. Accurate measurement and recording of instrumentation data cannot be overly emphasized. Suggested forms for recording the data are attached to this section as FIGURES II-8, II-9, and II-10 for Seepage Reading Record, Piezometer Reading Record, and Crest Movement Survey Record respectively. The forms shown in the Dam Safety Manual, Office of the State Engineer, Publication, 1988, can also be used.

b. The dam owner taking the reading should immediately reduce and plot the data on the relevant graphs to see if the readings make any sense or if there are any anomalies that indicate an emerging problem that should be resolved by an engineer. This will provide an opportunity to recheck the data for a reading error or to take appropriate action.

4. Analysis of data: The data should be reduced and plotted on appropriate graphs and maintained by the owner. These graphs should be reviewed by the owner's engineer for comment and sent to the State Engineer annually.

FIGURE II-8
FIELD SEEPAGE DATA RECORD

RESERVOIR____ DATE_______________
COMPANY____
WATER DIVISION_________ DAMID_____________________

Date	Observer	Reservoir Level		Outlet		Seepage Sta_____			Seepage Sta_____			Remarks
		Gage Height (feet)	Elevation (feet)	Flume Gage (feet)	Discharge (cfs)	Gage Reading (feet)	Flow Rate (gpm)	Quality	Gage Reading (feet)	Flow Rate (gpm)	Quality	

FIGURE II-9
FIELD PIEZOMETER DATA RECORD

RESERVOIR____ DATE______________
COMPANY____
WATER DIVISION________ DAMID______________________

Date	Observer	Reservoir Water Level (feet)	Piezometer No. 1 Station______________________ Offset______________________ El. Top Casing________________ Total Depth _________________		Piezometer No. 2 Station______________________ Offset______________________ El. Top Casing________________ Total Depth _________________		Piezometer No. 3 Station______________________ Offset______________________ El. Top Casing________________ Total Depth _________________		Piezometer No. 4 Station______________________ Offset______________________ El. Top Casing________________ Total Depth _________________	
			Depth to Water (feet)	Water Elevation (feet)	Depth to Water (feet)	Water Elevation (feet)	Depth to Water (feet)	Water Elevation (feet)	Depth to Water (feet)	Water Elevation (feet)

FIGURE II-10
FIELD MONUMENT SURVEY DATA RECORD

RESERVOIR_______________________________________ DATE_____________
COMPANY____
WATER DIVISION________ DAMID_____________________

Monument Point Number	Station	Initial Survey Data			Survey Date______			Changes		
		Elev. (ft)	Coordinates		Elev. (ft)	Coordinates		Elev. (ft)	North (ft)	East (ft)
			North (ft)	East (ft)		North (ft)	East (ft)			

A positive (+) value in "Changes" indicates an upward vertical movement or a horizontal movement to the North or East direction.
A negative (-) value in "Changes" indicates a downward vertical movement or a horizontal movement to the South or West direction.

J. EMERGENCY PREPAREDNESS PLAN

1. An Emergency Preparedness Plan, or EPP, is a formal plan that identifies potential emergency conditions at dam, and prescribes the procedures to be followed to save lives, and minimize property damage, in the event the dam fails. Despite the efforts to provide for the safety of dams through control of design and construction, and periodic safety evaluations of dams, our state has experienced catastrophic failure of dams. Therefore, it is necessary to be prepared for reacting to conditions at dams which could lead to their failure. By pre-planning the coordination of actions by the dam owners and the responsible local, State and Federal officials, timely notification, warning, and evacuation can occur which will save lives and minimize property damage.

2. Rule 16 from the State Engineer's Rules and Regulations for Dam Safety and Dam Construction requires that an EPP be prepared for existing Class I and Class II dams. In addition, Rule 10, Acceptance of Construction, requires that a plan be prepared before the State Engineer will approve these classes of dams for storage.

3. The State Engineer has provided a "Model for Preparing a Dam Safety Emergency Preparedness Plan" which is used by the owners of dams to prepare their plans. This document is not included in this guideline, however a copy is available at the Denver Office of the State Engineer, and Division Engineer’s offices. The dam owner is encouraged to prepare as much of the plan as possible because it is the process of preparing the plan that helps the dam owner to be prepared for an emergency.

PART III

CONSTRUCTION

A. CONSTRUCTION QUALITY CONTROL

1. Purpose: The extent of the construction control should be the same for all dams, however regulation requirements are based on the size and hazard classification of the dam. Construction quality control which includes observation and materials testing during construction cannot be overly emphasized. Preparation of detailed plans and specifications are only the first-half of the process. The second-half is the task of the construction team to construct a safe and functional dam according the designer's criteria but modified as necessary according to unanticipated conditions that were not identified during the original site investigation.

2. Construction Schedule: The construction schedule requires cooperation among all the parties especially in quality control. To facilitate coordination, the regulations require that no less than 30 days prior to construction, the project engineer shall submit a general plan for construction observation to the State Engineer for his review and approval. The State Engineer will provide written comments and approval within 10 working days. The construction observation plan includes:

a. The date when construction is expected to begin exclusive of mobilization.

b. The names and qualifications of the project engineer and staff in charge of construction.

c. The construction observation schedule. This includes discussion of the frequency of site visits by the responsible project engineer and staff.

d. An observation plan for an engineering geologist or geologist to inspect and observe the exposed foundation and cutoff trench for changed conditions.

e. Provisions for the gate manufacture to inspect the installation of the gate unless waived by the State Engineer.

f. A list of testing firms and personnel that will sample and conduct the material tests.

g. A list of applicable testing processes and standards including the frequency of tests for each material. Test frequency should be based on the volume of materials placed that day and a daily minimum, including tests of materials off site if applicable.

4. Preconstruction Meeting for Class I Dams: Construction of Large, Intermediate and Small Class I dams requires close coordination among the contractor, design or project engineer, quality control engineer, and the office of the State Engineer. To facilitate the cooperation, the Rules and Regulations require the project engineer, contractor and the State Engineer to meet no less than one week prior to construction. During this meeting, the State Engineer will discuss the roles of the State Engineer, owner's project engineer, and the contractor to ensure that the responsibilities and authority relationships are clearly established. In addition, a tentative list of items the State Engineer will want to observe during construction will be provided including a list of state personnel to contact concerning any matters of construction. Below are listed the items that should be available at the preconstruction meeting:

a. Project engineer's construction quality control plan
b. Contractor's diversion and care of stream plan

c. Project engineer's periodic reporting of construction plan.

d. State Engineer's List of inspection items & contacts

e. Contractors emergency preparedness and construction safety plan (recommended)

5. Class II and Class III Dams: The quality control requirements for these dams are significantly relaxed. The requirements for all dams are tabulated on Table III-1 Construction Control & Reporting Requirement, however the Rules and Regulations for Dam Safety and Dam Construction - "Rule 9- Construction Quality Control" provides a more detailed discussion of the requirements.

FIGURE III-1

CONSTRUCTION CONTROL & REPORTING REQUIREMENTS

Size of Dams: L = Large, I = Intermediate, S = Small, M = Minor

	HAZARD CLASS ------------- SIZE	CLASS I				CLASS II				CLASS III				CLASS IV			
		L	I	S	M	L	I	S	M	L	I	S	M	L	I	S	M
1	Engineer Construction Plan- 30 days before construction	x	x	x	1	1	1	1	1	1	1	1	2	2	2	2	2
2	State Engineer comments on plan due 10 working days after of plan	x	x	x													
3	Preconstruction meeting 7 days prior construction	x	x	x													
	Diversion and Care of Stream Plan Required	x	x	x													
	Contractor Construction Control Plan	x	x	x													
4	Maintain Construction Records	x	x	x	x	x	x	x	x	x	x	x					
5	Periodic Progress Report	x	x	x	x	x	x	x	x	x	x	x					
6	5 Day notice to State Engineer of key Inspection Items such as cutoff trench, etc.	x	x	x	x	x	x	x									
7	10 Day notice to State Engineer of Final Inspection	x	x	x	x	x	x	x	x	x	x	x	x	X	x	x	x
8	Final Construction Report and Completion Documents (per Rule 10)	x	x	x	x	x	x	x	x	x	x	x	x	X	x	x	x

x indicates a required activity for the hazard class and size of structure.
1 indicates a shorter than 30 day advance notice of construction maybe allowed.
2 indicates a notice of construction is required.

B. ROLE OF ENGINEERS DURING CONSTRUCTION

1. State Engineer: The State Engineer's function is to assure that downstream properties and lives are safe from the dam during construction and to assure the work is in compliance with approved plans and specifications. This is accomplished through the oversight of the owner's project engineer by the State Engineer as follows:

a. Construction observations

b. Review of construction progress reports

c. Review and approval of change orders

d. Discussions with the owner's project engineer

e. Performance of a final inspection at the completion of the project to verify that the construction has been completed as approved and to make a determination of the safe storage level.

2. Project Engineer: The owner's project engineer has the primary responsibility to assure construction quality and compliance with approved plans and specifications. This responsibility cannot be delegated. To meet this responsibility the project engineer provides the following:

a. Adequate observation and testing to assure compliance with approved plans and specifications.

b. Observation of site conditions and any changes as it relates to the approved plans and specifications.

c. Prepare change orders as necessary to accommodate differing site conditions or other unanticipated problems.

d. Provide authoritative presence on-site to make technical decisions and provide intra-organizational coordination.

e. Provide engineering judgement at the dam site.

f. Documentation of construction including periodic progress reports:

(1) Description of construction progress, weather conditions, problems encountered, resolution of problems, etc.

(2) Record a summary of test results for the period (Proctor density soil tests, insitu soil density tests, concrete cylinder breaks, aggregate tests, pertinent instrument readings, outlet conduit pressure test results, etc.)

(3) Representative photos of the work performed during the month. (May be color copies such as Xerox.)

C. END OF CONSTRUCTION AND DOCUMENTATION

1. Final Inspection Schedule: The project engineer shall provide no less than 10 days notice to the State Engineer of the date of the Final Construction Inspection.

2. Project Close Out and Documentation: After the final construction inspection has taken place and all corrected discrepancies are completed, the project engineer shall complete the following:

a. Provide a written letter to the State Engineer indicating that the project is complete and in general comports with the approved plans, specifications and change orders.

b. Prepare "AS-CONSTRUCTED" drawings at the completion of the project which includes a set of high quality mylar drawings and a set of paper prints all meeting the requirements of Rule 5 in both form and content.

c. Complete and file a final construction report which includes a list of design and construction changes, summaries of materials testing results and geologic observations, photographs showing the sequence of construction, a discussion of problems encountered and solutions used to correct the problems.

d. Provide a record of the location of permanent monuments and instrumentation as well as initial surveys and readings, if required.

e. Assure a schedule for monitoring the first filling of the reservoir, approved by the State Engineer, includes filling rates, elevations to hold water levels for observation, and a schedule for inspecting and monitoring the instrumentation during this period.

f. Assure a long term Instrumentation and Monitoring Plan, accepted by the State Engineer, contains provisions for the engineer to review the monitoring of instrumentation and performance of the dam for a period of at least 5 years. The remaining monitoring schedule shall be in conformance with Rule 15.C.(2) and (3).

g. An Emergency Preparedness Plan, if required, must be approved by the State Engineer before the dam is placed into service. A separate guide "Guideline for Preparing a Dam Safety Emergency Preparedness Plan" is available at the Office of the State Engineer.

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