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	Engineering and Design INFLOW DESIGN FLOODS FOR DAMS AND RESERVOIRS	
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DEPARTMENT OF THE ARMY
U. S. Army Corps of Engineers
CECW-EH Washington. D. C. 20314-1000

Regulation
No. 1110-8-2(FR) 1 March 1991

Engineering and Design
INFLOW DESIGN FLOODS FOR DAMS AND RESERVOIRS

1. Purpose and Scope. This regulation sets forth hydrologic engineering requirements for selecting and accommodating Inflow Design Floods (IDF) for dams and reservoirs.

2. Applicability. This regulation applies to all HQUSACE/OCE elements, major subordinate commands, districts, and laboratories having civil works responsibility.

3. References. Listed in Appendix A.

4. Terminology. Appendix B contains explanations of special terms used in this regulation. More complete glossaries may be found in the references.

5. General Policy. It is the Corps of Engineers policy that dams designed, constructed, or operated by the Corps will not create a threat of loss of life or inordinate property damage. Departures from accepted policy or practice will not be made in the design of a dam simply to reduce cost. Every phase of the planning, design, construction, and operation of a dam will be accomplished to assure that it is safe, efficient, and reliable.

6. Discussion.

a. The basis for application of design guidance is the policy set forth in paragraph five above. When a dam impounds water upstream from a populated area, a distinct hazard to that area from possible failure of the dam is created. This requires that extreme care be exercised in every phase of the engineering design, construction, and operation of the project to assure complete safety. Deliberately accepting a recognizable risk to life in the design of a dam simply to reduce the cost of the structure has been generally discredited from an ethical and public welfare standpoint. Legal and financial capability to compensate for economic losses associated with dam failure is inadequate justification for accepting such a risk, when hazard to life is involved. There are numerous examples where failure of even small dams with small storage capacity has resulted in large loss of life and heavy property damage. It is essential that design guidance be geared to safety, considering both the upstream impacts of an imposed ponding and the downstream consequences of dam failure.

This regulation supersedes EM 1110-2-1101 (19 February 1968) Design Criteria for Systems of Small Dams.

b. A large earthen embankment dam can be cited as the upper end of the scale insofar as avoidance of risk is concerned. For such a structure, a design should be established on the basis that the possible loss of life is obviously unacceptable and that potential damages could approach disaster proportions; and, therefore, failure cannot be tolerated. At the other end of the scale would be a small dam built in an agricultural area where failure would not jeopardize human life nor create damages beyond the capabilities of the owner to recover. For such a structure, design criteria can be established that allows for the possibility of failure. Between these two extremes there might appear to be a wide range of intermediate types of dams with established guidance to govern their design, but such is not the case. The requirement that a dam failure must not present a hazard to human life remains a fixed condition that must be met by all designs.

7. Safety Dam Standards.

a. General. The selection of IDF's and the design of dam elements necessary to meet minimum safety requirements will conform to one of the following standards. The standard employed will be governed by circumstances associated with specific projects and associated upstream and downstream developments.

b. Standard 1: Standard 1 applies to the design of dams capable of placing human life at risk or causing a catastrophe, should they fail. Dam height with appropriate freeboard, spillways, regulating outlets, and structural designs will be such that the dam will safely pass an IDF computed from probable maximum precipitation (PMP) occurring over the watershed above the dam site.

c. Standard 2: Standard 2 applies principally to the design of run-of-river hydroelectric power or navigation dams, diversion dams, and similar structures where relatively small differentials between headwater and tailwater elevations prevail during major floods. While no unique IDF needs to be established, the structure should be able to safely pass major floods, typical of the region. without excessive structural damage and remain operable. Project design will be baaed on upstream impact, sediment, dredging, life cycle cost, operational, and other considerations.

d. Standard 3: Standard 3 applies to dams where an analysis clearly demonstrates that failure could be tolerated at some flood magnitude. The recommended plan should be for a dam which meets or exceeds a base safety standard. The base safety standard will be met when a dam failure related to hydraulic capacity will result in no measurable increase in population at risk and a negligible increase in property damages over that which would have occurred if the dam had not failed. Determination of the IDF that identifies the base safety standard will require definition of the relationship between flood flows and adverse impacts (population at risk and property damages) with and without dam failure for a range of floods up to the probable maximum flood (PMF). Appropriate freeboard will be included for all evaluations. Selection of a base condition predicated on the risk to life from dam failure will require supporting information to demonstrate the increment of population that would actually be threatened. The evaluation should distinguish between population downstream of a dam and the population that would likely be in a life threatening situation given the extent of prefailure flooding, evacuation opportunities, and other factors that might affect the occupancy of the incrementally inundated area at the time the failure occurs. The occurrence of overtopping floods must be relatively infrequent to make standard 3 acceptable. One-half of the PMF is the minimum acceptable IDF for standard 3 dams.

e. Standard 4: Standard 4 is applicable to many small recreational type lakes and farm ponds generally containing twenty acre-feet or less of storage. IDF's for small projects corresponding to Standard 4 are usually based on rainfall-runoff probability analyses and may represent events of fairly frequent occurrence. In such cases it is often preferable to keep freeboard allowances comparatively small, in order to assure that the volume of water impounded will never be large enough to create a major flood wave if the dam is overtopped and fails. In some instances adoption of Standard 4 may be mandatory in spite of the owner's desire for a higher dam to reduce the frequency of damage to the structure due to overtopping floods, unless appropriate safety to downstream interests can be assured.

8. Inflow Design Flood Development and Application.

a. Under procedures used by the Corps of Engineers, IDF estimates consist of hypothetical flood hydrographs developed from rainfall intensity, duration, area relationships (and snowmelt if pertinent) and runoff characteristics applicable to the drainage basin involved. Generalized rainfall criteria are used, insofar as applicable, to assure consideration of regional influences on storm potentials. Special hydrometeorological studies of individual project basins are made if unusual conditions in a particular drainage basin or lack of refinement in generalized estimates warrant such action. corps of Engineers field offices will submit requests' to HQUSACE (CECW-EH) for any assistance needed from the Hydrometeorological Section of the National 'Weather Service (Hydromet) in the development of specialized meteorological analyses. Corps field offices will use generalized or specialized rainfall PMP amounts developed by Hydromet to compute a PMF.

b. Rainfall to runoff conversion (unit hydrographs) and loss rates will be derived to correspond to patterns favorable for rapid concentrations of runoff from the drainage basin. Reservoir inflow unit hydrographs for IDF determinations should be peaked 25 to 50 percent to account for the fact that unit hydrographs are usually derived from smaller floods. Inflow design flood hydrographs will be computed as inflow into a full reservoir in order to allow for the effects of the reservoir in accelerating concentration of runoff under critical conditions. This requires separate inflow hydrographs for tributaries, main stem, local areas, and the pool area. It is common practice to assume a zero travel time through the pool unless the pool is very long.

c. The water control plan assumed in routing the IDF should be consistent with the water control plan that is expected to be followed in actual practice. Any uncertainties that might influence safety of operation should be evaluated by a sensitivity analysis of the maximum expected water surface elevation during occurrence of the IDF. Foreknowledge *of* rainfall will not be assumed.

d. Reservoir regulating outlets should not be assumed operable during the occurrence of an IDF, unless they are specifically designed for such purpose.

e. When a spillway or outlet is gated the possibility that personnel will not be present or able to regulate a project in a prescribed manner must be considered. It should not be assumed that regulating outlets or spillway gates would be attended or that water control would be reliable during the occurrence of an IDF if the lag time between intense rainfall and occurrence of peak reservoir inflow is less than 12 hours. Therefore, misoperation will be considered, tested, and consequences determined. A regulation plan that assumes all communication is interrupted and the operator must operate with only knowledge of pool elevation and pool rate of rise will be developed, and the design will be tested using this plan.

f. An antecedent flood will be assumed to occur prior to the IDF and will be developed using sound hydrologic engineering principles. Reallocations of flood control storage to some other use in the future that may result in higher pool levels at the beginning of the IDF should be considered. Experience has demonstrated that an unusual sequence of floods can result in filling all or a major portion of the flood control storage in a reservoir immediately before the beginning of the IDF. In view of the uncertainties involved in estimating reservoir levels that might reasonably be expected to prevail at the beginning of the IDF, the minimum starting elevation for routing the IDF will be assumed as the full flood control pool level or the elevation prevailing five days after the last significant rainfall of a storm that produces one-half the IDF, whichever is most appropriate. If the IDF estimate is associated with a particular season, the determination of initial pool level will consider flood conditions during comparable times of the year. A comparison of surcharge elevations computed under alternative starting elevation assumptions is required to reveal the sensitivity of the maximum pool to the starting elevation.

9. Freeboard on Dams:

a. General, Freeboard is an integral part of any dam. The objective in selection of design freeboard is to assure that failure of the dam will not result from wind set-up, wave action, uncertainties in analytical procedures, and uncertainties in project function in combination with the most critical pool elevation. Zero over-wash is not always required under infrequent high pool conditions, but it is required that the over-wash will not be of such a magnitude and duration as to threaten the safety of the dam. Geotechnical considerations, e.g. settlement and camber, may require an additional increment of dam height above the freeboard described herein.

b. For reservoirs with surcharge above the full pool, where wave overtopping would not be of such magnitude or duration to endanger integrity of the dam, the freeboard, except as required by c. below, will be a minimum of three feet (embankment and concrete dams) or greater as determined by considerations in a. above.

c. Reservoirs with surcharge pool elevations within three feet of the maximum pool level for a substantial period of time, 36 hours or longer, have increased probability that high winds in the critical fetch may coincide with this level. Therefore when the IDF pool hydrograph is within three feet of the maximum pool for 36 hours or longer or where the project has been designed with little surcharge for the maximum pool above the full pool elevation, the minimum freeboard will be five feet for embankment dams and three feet for concrete dams or greater as determined by considerations *in* a. above.

10. Additional Project Design Considerations. The analysis leading to the selection of an appropriate IDF and project design will generally be an iterative process. This process will consider several factors including downstream impacts, upstream impacts, cost, and other design considerations. Some other relevant hydrologic engineering considerations are as follows:

a. A cost analysis will be performed to select the project design with the least life cycle cost' that will pass the IDF selected in accordance with the above policies, requirements, and considerations.

b. The selected project design must always result in the same or smaller discharges than those that would have occurred without the project under the same flood conditions up to the IDF.

c. An important objective of a project design will be to limit storage accumulation during floods to avoid excessive damage or a threat to life within reservoir areas upstream from the dam. During the IDF selection and project design process careful consideration will be given to limiting the hazard to populated areas located in the upstream pool area to acceptable limits. A reservoir pool will not create a risk to human life or excessive damage. The analysis of upstream flood impacts within the pool area will consider warning time, rate of rise, and depth for all floods up to the PMF.

11. Approval of IDF. Inflow design flood and top of dam determinations that fully comply with the policies and other requirements of this regulation will be reviewed and approved by the division water management branch. Information copies of the approval document along with all supporting correspondence will be forwarded to CECW-EH within 15 days of the division approval. If a

district or division contemplates any deviations from this regulation, if there are questions of interpretation, or if a district and division disagree, CECW-EH should be immediately consulted. Deviations from this regulation or normal Corps practice will be approved by CECW-EH and should not be communicated in any way for any reason to any person or entity outside the Corps until such approval has been obtained.

12. Reporting. Reporting of IDF determinations and dam design will be through the normal reporting process as defined in references 1 and 2. Reporting requirements are outlined in references 1, 2, 5, and 8. In addition to the above, reports should provide the following:

a. IDF rainfall and runoff, in tables and graphs.

b. Graphs of without project dam site unit hydrograph and reservoir inflow unit hydrograph.

c. Graphs of IDF hydrographs: reservoir inflow hydrograph, pool stage hydrograph, outflow hydrograph, and without project dam site hydrograph.

d. Antecedent flood development and routing: present information similar to a through c above.

e. Water control plan on which routing of the antecedent flood and IDF are based.

f. Discussion and justification for the dam safety standard, selection of the antecedent flood, and the IDF.

g. If a dam design is to be based on the Class 3 safety standard, provide inundation areas, population at risk, economic damages, etc., essentially in accordance with Guidelines for Evaluating Modifications of Existing Dams Related to Hydrologic Deficiencies, Oct 1986, IWR Report 86-R-7.

h. Results of sensitivity analyses assuming various types of misoperations and IDF routing starting elevations.

i. Freeboard computations including fetch, wind velocity, setup, and runup.

FOR THE COMMANDER:

2 Appendices
APP A - List of References
APP B - Glossary - Explanation of Terms

ROBERT L. HERNDON
Colonel, Corps of Engineers
Chief of Staff

APPENDIX A

LIST OF REFERENCES

1. ER 1110-2-1150: Engineering After Feasibility Studies.

2. ER 1110-2-1460: Hydrologic Engineering Management.

3. EM 1110-2-1405: Flood-Hydrograph Analysis and Computations.

4. EM 1110-2-1406: Runoff from Snowmelt.

5. EM 1110-2-1411 (Civil Works Engineer Bulletin): Standard Project Flood Determinations.

6. EM 1110-2-1602: Hydraulic Design of Reservoir Outlet Works.

7. EM 1110-2-1603: Hydraulic Design of Spillways.

8. EM 1110-2-1605: Hydraulic Design of Navigation Dams.

9. EM 1110-2-3600: Management of Water Control Systems.

10. ETL 1110-2-230: Hydrologic and Hydraulic Engineering for Survey Investigations.

11. FEMA 148 (Feb 1988): Glossary of Terms for Dam Safety, prepared by Interagency Committee on Dam Safety Task Group on Glossary of Terms.

12. Criteria and Practices Utilized in Determining the Required Capacity of Spillways (1970) prepared by USCOLD Committee on "Failures and Accidents to Large Dams, other than in connection with the Foundations".

13. Determination of Spillway Requirements for High Dams, by Gail A. Hathaway (March 1950). distributed to Corps of Engineers offices with CW Engineer Bulletin 50-6, issued 9 June 1950.

14. Federal Guidelines for Selecting and Accommodating Inflow Design Floods for Dams, prepared by The Working Group on Inflow Design Floods Subcommittee 1 and the Interagency Committee on Dam Safety.

15. Unit Hydrographs: Part 1, Principles and Determination. U. S. Army Engineer District, Technical Report on CWI Project 152, Balt., MD (1963).

APPENDIX B

GLOSSARY

EXPLANATION OF TERMS

Antecedent flood:	A flood or series of floods assumed to occur prior to the occurrence of an IDF.
Base Safety Standard:	The IDF where there is no significant increase in adverse consequences from dam failure compared to non-failure adverse consequences.
Breach:	A gap, rift, hole, or rupture in a damming structure; providing a break; allowing water stored behind the dam to flow through in an uncontrolled and unplanned manner.
Catastrophe:	A sudden and great disaster causing misfortune, destruction, or irreplaceable loss extensive enough to cripple activities in an area.
Dam:	A barrier that obstructs, directs, retards, or stores the flow of water. Usually built across a stream.
Failure:	Destroyed and made useless, ceases to function as a dam. More severe and hazardous than a breach.
Fetch:	The area in which waves are generated by a wind having a fairly constant direction and speed.
Freeboard:	Vertical distance between the maximum pool stillwater surface elevation and the top of the dam, without camber.
Full Pool:	The reservoir level that would be attained when the reservoir is fully utilized for all project purposes, including flood control.
Hydrograph:	A graphical representation of the stage or discharge as a function of time at a particular point on a watercourse.
Inflow Design Flood (IDF):	The flood hydrograph used in the design of a dam and its appurtenant works particularly for sizing the spillway and outlet works, and for determining maximum temporary storage and height of dam requirements.
Maximum Pool:	The highest pool elevation resulting from the IDF.
Maximum Wave:	The highest wave in a wave group.

Probable Maximum Flood (PMF):	The most severe flood that is considered reasonably possible at a site as a result of hydrologic and meteorologic conditions.
Probable Maximum Precipitation (PMP):	Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographic location at a certain time of year.
Regulating Outlets:	Outlet works or just outlet; an opening or structure by which water is discharged from a dam. The release rate may be controlled by gates or by the outlet geometry and pool elevation. Designed primarily for normal operation of a dam and reservoir for water quality, low flow, and flood control' releases.
Risk:	The exposure to injury or loss; a hazardous or dangerous chance.
Runup:	The vertical distance above the setup that the rush of water reaches when a wave breaks on the dam embankment.
Setup (Wind):	The vertical rise in the stillwater level at the upstream face of a dam caused by wind stresses on the water surface.
Significant Wave Height:	The average height of the one-third highest waves of a given wave group.
Spillway:	Any passageway, channel, or structure designed to discharge surplus water from a reservoir. May be operationally complementary to and/or structurally combined with regulating outlets. May be gated or uncontrolled.
Surcharge:	Any storage above the full pool.
Unit hydrograph:	A hydrograph representing a runoff volume of one inch resulting from a storm of a specified area1 distribution and runoff duration.