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Dam Safety Publication No. 3

Rules and Regulations of the Missouri Dam and Reservoir Safety Council

MISSOURI DEPARTMENT OF NATURAL RESOURCES
Geological Survey and Resource Assessment Division
Dam and Reservoir Safety Program

Cover photo: Jamesport City lake dam in Daviess County, Missouri.
Dam and Reservoir Safety Program file photo.

Dam Safety Publication No. 3

RULES AND REGULATIONS OF THE MISSOURI DAM AND RESERVOIR SAFETY COUNCIL

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INTRODUCTION

The Dam and Reservoir Safety Council and the Dam and Reservoir Safety Program within the Missouri Department of Natural Resources were established by House Committee Substitute for House Bill 603 as passed by the first regular session of the 80th General Assembly. The bill was signed by the governor and subsequently became law on September 28, 1979. This law is Sections 236.400 through 236.500 in the Revised Statutes of Missouri as printed in the 1986 Supplement. The Dam and Reservoir Safety Program was assigned to the Geological Survey and Resource Assessment Division within the Department of Natural Resources for administration.

The Governor began appointment of the first Council during April of 1980. Employment of the Chief Engineer and initiation of recruitment for the additional authorized staff commenced in July 1980. A working Council with a quorum of four members had been appointed by September 1980.

From September 1980 to August 1981 the Council, with help from the Chief Engineer and his staff, promulgated the first set of rules. These rules provide the information that is necessary in order to implement the law. These rules became effective on August 13, 1981 and are contained in the Code of State Regulations under Title 10, Division 22, Chapters 1 through 3.

In June 1984, the seventh member of the Council was appointed by the Governor, and the first full seven member council meeting was held in July 1984. From January 1984 to December 1984, the Council, with help from the Chief Engineer and his staff, made extensive revisions to the August 13, 1981 edition of the rules. These revisions became effective on January 1, 1985 and are contained in the Code of State Regulations under Title 10, Division 22, Chapters 1 through 4. The Council has taken action on four other occasions to make minor modifications to the rules. These revisions became effective on January 1, 1987; January 1, 1989; January 1, 1991; and June 9, 1994.

The Dam and Reservoir Safety Council is a non-paid policy-making body appointed by the Governor with the consent of the Senate. Communication with the Council is normally handled through the paid staff, which is directed by the Chief Engineer. Questions, comments, requests, and other inquiries should be addressed to the Chief Engineer for action or referral to the Council. The Chief Engineer may be contacted at the following address or telephone number.

Chief Engineer
Dam & Reservoir Safety Program
Missouri Department of Natural Resources
PO Box 250
Rolla, MO 65402-0250
573/ 368-2175

CODE OF STATE REGULATIONS – RULES
TITLE 10 – DEPARTMENT OF NATURAL RESOURCES
DIVISION 22 – DAM AND RESERVOIR SAFETY COUNCIL

CHAPTER 1 – ORGANIZATION, DEFINITIONS AND IMMUNITY

10 CSR 22-1.010 General Organization

PURPOSE: The purpose of this rule is to comply with section 536.023, RSMo (1978) which requires each agency to adopt as a rule a description of its operation and the methods whereby the public may obtain information or make submissions or requests.

(1) Section 236.410, RSMo (1986) establishes a Dam and Reservoir Safety Council of the state of Missouri. The council consists of seven (7) members appointed by the governor with the advice and consent of the Senate. The council holds a minimum of four (4) regular meetings each year and such special meetings and hearings as the council chairman may deem necessary.

(2) The Missouri dam and reservoir safety law and rules, regulations, guidelines and standards provide for the construction, management and operation of dams and reservoirs in a manner which will provide adequate protection of public safety, life or property. To achieve this purpose the council has statutory powers as listed in sections 236.405 and 236.415, RSMo (1986) for policy making, adopting rules, regulations, standards and guidelines and issuing of permits.

(3) The Department of Natural Resources is authorized under section 236.405, RSMo (1986) to administer and enforce all rules, regulations, standards and guidelines adopted by the council and assist the council in achieving its statutory duties. The department has designated the dam and reservoir safety program as the agency within the department responsible for administering the dam and reservoir safety law. The director of the Department of Natural Resources appoints a chief engineer who is the dam and reservoir safety program director and a staff as provided in section 236.405, RSMo (1986). The chief engineer and staff provide day-to-day operation of the dam and reservoir safety program.

(4) Among its operations, the dam and reservoir safety program performs administrative and technical functions including: review permit applications and recommend approval or denial of such applications; inspect dams and reservoirs; enforce the law and all rules, regulations, standards and guidelines adopted pursuant to Chapter 236, RSMo (1986); employ necessary staff, develop facts as may be required by the council; recommend rules, regulations, standards and guidelines required by Chapter 236, RSMo (1986); mitigate or eliminate unsafe dam or reservoir conditions; and other functions as described in section 236.420 to 236.500, RSMo (1986).

(5) Requests for permit applications, requirements or other permit information, copies of these rules and the dam and reservoir safety law, dam inspections, technical information and assistance, requests for public hearings and any other submissions are to be made to the Department of Natural Resources, Dam and Reservoir Safety Program, PO Box 250, Rolla, MO 65402-0250.

Auth: chapter 236.RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981.

10 CSR 22-1.020 Definitions

PURPOSE: The following terms when used in rules, regulations, standards and guidelines adopted by the Dam and Reservoir Safety Council pursuant to the "dam safety law" shall have the meaning respectively ascribed to them by this section.

Editors note: The secretary of state has determined that the publication of this rule in its entirety would be unduly cumbersome or expansive. The entire text of the rule has been filed with the secretary of state. The entire text of the rule may be found at the headquarters of the agency and is available to any interested person at a cost not more than the actual cost of reproduction.

(1) **"Agency engineer"** means an experienced engineer, not necessarily registered as a professional engineer in Missouri, who works for an engineering division of a state or federal agency regularly engaged in dam and reservoir design and construction for soil and water conservation or irrigation or relating to wildlife conservation.

(2) **"Agricultural dam"** means any dam, the primary use of which is to impound water for use in irrigation, livestock watering, or commercial fish rearing and sale.

(3) **"Alterations", "repairs",** or either means such alterations or repairs as affect the safety of a dam or reservoir, or public safety, life or property.

(4) "**Appurtenant works**" means the structures or materials incident to or annexed to dams that are built or maintained in connection with such dams and which are used primarily in connection with their proper operation, maintenance or functioning. This includes, without limitation, such structures as spillways, either in the dam or separate therefrom; the reservoir rim; low level outlet works; and water conduits such as tunnels, pipelines or penstocks, either through a dam or its abutments.

(5) **"Area capacity curves"** means graphic curves, which show the relationship between reservoir surface area and the storage capacity of the reservoir at given elevations.

(6) **"Chief engineer"** means the head of the dam and reservoir safety program of the Department of Natural Resources or his representative.

(7) **"Commercial Fish Rearing"** reservoir means a reservoir which was designed specifically for fish rearing purposes and the primary use is to provide water for commercial fish rearing and sale to other parties in a "for profit" venture. This does not include activities such as sport fishing.

(8) **"Construction permit"** means a written authorization issued by the council giving the owner the right to construct, alter, enlarge, reduce, repair or remove a dam or reservoir or appurtenances thereto, with such conditions as are necessary to adequately protect the public safety, life, property, the dam or reservoir.

(9) **"Conventional dam"** means any dam other than an industrial water retention dam.

(10) **"Council delegate"** or **"authorized representative"** means an individual, usually the chief engineer, authorized by the council to act in its behalf.

(11) **"Crest"** or **"dam crest"** means the top surface of the dam.

(12) **"Crest elevation"** or **"dam crest elevation"** means the lowest elevation of the crest exclusive of the spillway(s).

(13) **"Dam"** means any artificial or man-made barrier which does or may impound water, and which impoundment has or may have a surface area of fifteen (15) or more acres of water at the water storage elevation or which is thirty-five feet (35') or more in height measured either from the natural bed of the stream or watercourse or lowest point on the toe of the dam (whichever is lower) up to the crest elevation, together with appurtenant works. Sections 236.400 and 236.500 shall not apply to any dam which is not or will not be in excess of thirty-five feet (35') in height or to any dam or reservoir licensed and operated under the Federal Power Act.

(14) **"Dam and Reservoir Safety Council"** referred to as the "council" means seven (7) members appointed by the governor for purposes of implementing the dam safety law.

(15) **"Dangerous Dam or Reservoir"** is a dam or reservoir which is in an advanced state of deterioration such that if deterioration continues, the threat of dam failure and flooding would be imminent and substantial.

(16) **"Department"** means the Department of Natural Resources.

(17) **"Downstream environment zone"** means the area downstream from a dam that would be affected

by inundation in the event the dam failed when filled to the emergency spillway crest elevation, or to the dam crest elevation, in the absence of an emergency spillway.

(18) **"Earthquake Intensity"** means Modified Mercalli intensity which is used to describe the degree of shaking a dam will experience.

(19) **"Enforcement Order"** means a written directive issued by the council or the chief engineer to the owner of a dam for correction of defects in the dam or reservoir which have been determined to make the structure a threat to public safety, life or property. The order will contain specific actions with which the owner must comply to remove the threat the dam or reservoir poses to public safety, life or property.

(20) **"Enlargement"** means any change in or addition to an existing dam or reservoir, which raises the height of the dam, increases the watershed for the reservoir or raises the water storage elevation of the water impounded by the dam or reservoir.

(21) **"Environmental class"** means classification of the downstream environment zone based on the contents of that zone (see 10 CSR 22.2.040(1)). Class I represents the most severe threat to public safety, life or property and Class III represents the least threat.

(22) **"Factor of safety"** means the resultant of the summation of the forces resisting failure divided by the summation of the driving forces tending to cause failure.

(23) **"Freeboard"** means the difference in elevation between the dam crest elevation and the water storage elevation in the reservoir.

(24) **"Height"** or **"height of dam"** means the difference in the elevation of either the natural bed of the stream or watercourse or the lowest point on the toe of the dam (whichever is lower) and the dam crest elevation.

(25) **"Industrial building"** means a permanent, enclosed structure used by groups of workers usually involved in some type of manufacturing, processing or industrial related process.

(26) **"Industrial water retention dam"** means a dam used to retain the solids transported as water-borne industrial byproducts and the associated water. This includes, but is not limited to, tailings dams, slime impoundments and settling ponds.

(27) **"Inundation"** means water, two feet (2') or more deep, over the general level of the submerged ground affected outside the stream channel.

(28) **"Inspection"** means scheduled and unscheduled examinations of a dam and reservoir with the primary objective of making safety observations and recording them in a written description.

(29) **"Irrigation Reservoir"** means a reservoir whose primary use is to provide water for the irrigation of agricultural lands for the production of grains, hay, pasture, fruits, vegetables and animal feeds which are for sale or to be used by the owner.

(30) **"Law"** means the dam and reservoir safety law, as contained in chapter 236, RSMo, and all rules, regulations, standards and guidelines adopted thereto.

(31) **"Liquefaction"** is a condition where a soil will undergo continued deformation at a constant low residual stress or with low residual resistance, due to the build-up and maintenance of high pore water pressures, which reduce the effective confining pressure to a very low value.

(32) **"Livestock Water Reservoir"** means a reservoir whose primary use is to provide water for livestock that are raised for breeding or marketing purposes.

(33) **"Maintenance"** means the proper keeping of all aspects of a dam or reservoir and appurtenances thereto, that pertain to safety, in a state of repair and working order as necessary to comply with the law and any permit issued thereunder and to protect public safety, life or property.

(34) **"Modification"** or **"modifications"** means changes or revisions to the design, construction, maintenance, operation or repair or the alteration, enlargement, reduction, removal or natural physical change that may occur to a dam or reservoir that were not included in the approved plans for the construction permit, or such changes or revisions to a dam or reservoir where a registration or safety permit is in effect or required hereunder, if such changes or revisions would endanger public safety, life or property as a result of creating a potential

failure in the dam or reservoir, except that modification or modifications do not mean or include approved anticipated enlargements, outlined by design plans and specifications submitted and approved with the original application for a construction, safety or registration permit for industrial water retention dams and reservoirs.

(35) **"Observable defects"** are those defects which would be detectable by an experienced professional engineer making an on-site visual inspection of the dam in accordance with current engineering, geologic and construction practices.

(36) **"Owner"** or **"dam owner"** means a person who owns, controls, operates, maintains, manages or proposes to construct a dam or reservoir including: the state and its departments, institutions, agencies, and political subdivisions, but not the United States government; a municipal or quasi-municipal corporation; a district; a public utility; a natural person, firm, partnership, association, corporation, political subdivision or legal entity; the duly authorized agents of leasees, or trustees of any of the foregoing; or receivers or trustees appointed by any court for any of the foregoing.

(37) **"Permanent dwelling"** means a dwelling occupied at least ninety (90) days a year.

(38) **"Permit"** means construction, safety or registration permit.

(39) **"Permit application"** or **"applicant"** means an owner who applies for a construction, safety or registration permit.

(40) **"Probable maximum acceleration"** means the horizontal acceleration developed at a dam as a result of an earthquake with a probability of occurrence similar to the probable maximum precipitation. The probable maximum acceleration is readily available from a Corps of Engineers Report entitled "Earthquake Potential of the St. Louis District – Ground Motion Supplement" which is on file with the chief engineer of the Dam and Reservoir Safety Program. *(See Editors Note.)*

(41) **"Probable maximum precipitation"** or **"PMP"** means the precipitation that may be expected from the most severe combination of critical meteorological conditions that are reasonably possible in an area. The probable maximum precipitation (PMP) is readily available from the National Weather Service in Hydrometeorological Report 51, *"Probable Maximum Precipitation Estimates, United States East of the 105h Meridian." (See Editors Note.)*

(42) **"Public building"** means a permanent, enclosed structure used by the general public but not necessarily owned by the public.

(43) **"Registration Permit"** means a permit issued for a period not to exceed five (5) years by the council to the owner of a dam or reservoir in existence or in the progress of construction on August 13, 1981 or which becomes subject to the law for such dams and reservoirs by a change in factors or circumstances subsequent to that date. Such permits shall only be issued for dams which are in properly maintained condition or which have made and complied with recommendations for corrections of observed defects of the dam or reservoir and have been examined and approved in accordance with the law.

(44) **"Reservoir"** means any basin, including the water, which contains or will contain the maximum amount of water impounded by a dam.

(45) **"Safety Permit"** means a permit issued to the owner of a dam for a period of five (5) years, or less if safety considerations so require, by the council indicating that the dam meets the requirements of the law, and containing such conditions as to operations, maintenance and repair as are necessary to adequately protect public safety, life and the dam or reservoir.

(46) **"Seepage"** means the migration of water though a dam or foundation.

(47) **"Significant Modification"** means changes, alterations, or modifications to an existing dam or reservoir or changes to the construction documents for a new dam. These include but are not limited to: changes in the location of the dam or reservoir, changes in the storage capacity or drainage area, changes in the capacity of the spillway system, modification of the embankment slopes, changes in the height of the dam or structure or the use of different construction methods or procedures than those submitted with the permit application.

(48) **"Spillway"** means any passageway, channel, or structure, open or closed, or both, designed expressly or primarily to discharge excess water from a reservoir after the water storage elevation has been reached.

(49) **"Spillway design flood"** or **"SDF"** means the specified flood discharge that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in an area and for which the dam and reservoir are designed. The "SDF" is derived from the rainfall values given in Table 5.

(50) **"Stability"** means the properties of a dam or reservoir that cause it, when disturbed from a condition of equilibrium, to develop forces or moments that restore the original condition.

(51) **"Starter dam"** means a pervious or impervious dam constructed as the first phase in the building of an industrial water retention dam and reservoir.

(52) **"Storage"** means the volumetric capacity of the reservoir below the water storage elevation or other selected reference on the dam.

(53) **"Stream"** means any river, creek or channel, having well-defined banks, in which water flows for substantial periods of the year to drain a given area.

(54) **"Tailings"** means the material generated by a mining/milling operation, which is deposited in slurry form in an impoundment for storage and/or disposal or both.

(55) **"Tailings dam"** means an existing dam or reservoir used for the impoundment or retention of tailings or a proposed, existing or newly constructed dam and reservoir for which the anticipated or contemplated use is the impoundment or retention of tailings.

(56) **"Toe"** or **"toe of slope"** means the line of the fill (dam embankment) slope where it intersects the natural ground.

(57) **"Water"** means water, other liquids or tailings.

(58) **"Watercourse"** means a valley, swale, depression, or other low place in the topography occupied by flowing water during conditions of runoff.

(59) **"Water storage elevation"** means that elevation of water surface at the principal spillway, which could be obtained by the dam or reservoir were there no outflow and were the reservoir full of water.

(60) **"Watershed"** means the area that contributes or may contribute surface water to a reservoir.

Auth: sections 236.405 and 236.415, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985. Amended: Filed September 7, 1993, effective May 9, 1994.

10 CSR 22-1.030 Immunity of Officers

PURPOSE: The purpose of this rule is to restate the immunity from damages provided in section 236.475, RSMo (1986)

(1) In the absence of willful and wanton misconduct, no action shall be brought against the council, the chief engineer or his agents, or department employees or private individuals employed as consultants by the department for the recovery of damages caused by the partial or total failure of any dam or reservoir or through the use of operation of any dam or reservoir upon the ground that such person is liable by virtue of any of the following: the approval of a dam or reservoir or permits therefore; the issuance or enforcement or orders relating to maintenance, operation or repair of a dam or reservoir; control or regulation of a dam or reservoir; measures taken to protect against failure during an emergency; or denial of a permit.

Auth: sections 236.475, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981.

TITLE 10 – DEPARTMENT OF NATURAL RESOURCES
DIVISION 22 – DAM AND RESERVOIR SAFETY COUNCIL

CHAPTER 2 – PERMITS

10 CSR 22-2.010 Who Needs a Permit

PURPOSE: The purpose of this rule is to identify those persons who need to obtain a permit for their dam and reservoir and to identify those persons who do not need to obtain a permit for their dam and reservoir.

(1) The owner of a proposed new dam thirty-five feet (35') or more in height is required to obtain a construction permit and a safety permit for his dam and reservoir. The owner of an existing dam thirty-five feet (35') or more in height is required to obtain a registration permit within the time set forth in 10 CSR 22-2.020(2).

(2) By definition, the United States government is not considered an owner. Therefore, no federal dam and reservoir is regulated by section 236.400 to 236.500, RSMo (1986), and no permits are required.

(3) Agricultural dams are exempted from all permit requirements as long as the agricultural dam and reservoir continue to be used primarily for agricultural purposes, (see 10 CSR 22-1.020(2)). The owners of agricultural dams and reservoirs over thirty-five feet (35') in height must notify the council of their reliance on this exemption and their basis for application of this exemption to their dams. If an agricultural dam and reservoir is constructed after the effective date of the law, but subsequently becomes subject to the provisions of the law, the owner shall, prior to obtaining a registration permit, provide evidence that the dam meets the construction permit criteria in effect at the time the dam was constructed.

(4) Dams and reservoirs licensed and operated under the Federal Power Act are exempted from all permit requirements.

(5) Dams and reservoirs that were designed by and the construction monitored by an agency engineer (see 10 CSR 22-1.020(1)) do not need a construction permit but a set of plans shall be filed with the chief engineer prior to the initiation of the construction activity. These dams and reservoirs are required to have a registration or safety permit subsequent to construction.

(6) Industrial water retention dams (see 10 CSR 22-1.020(26)) and reservoirs regulated by another state agency or federal agency are exempted from all permit requirements. For the exemption to apply the industrial water retention dam and reservoir must be subject to safety inspections by the other state agency or federal agency and standards used must be at least as stringent as those required by the law. In addition the owner must notify the council that another agency is regulating his dam and reservoir and explain the basis for the exemption to apply.

Auth: sections 236.400, 236.405, 236.415, 236.435, 236.440, and 236.465, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985. Amended: Filed September 7, 1993, effective May 9, 1994.

10 CSR 22-2.020 Types of Permits

PURPOSE: The purpose of this rule is to describe the three (3) types of permits and their uses that the Dam and Reservoir Safety Council will issue.

(1) There are three (3) types of permits – registration permits, construction permits and safety permits and each one is intended to regulate a separate and distinct type of activity. A dam and reservoir will have only one (1) type of permit in effect at any given time although they may have more than one type of permit during their existence.

(2) Registration permits (see 10 CSR 22-1.020(43)) apply to and are required for the continued operation of a dam and reservoir that was in existence on the effective date of this paragraph, August 13, 1981. A registration permit also applies to and is required for structures which become subject to the provisions of the dam and reservoir safety law that were in existence prior to the date that they became sub-

ject to the law. Registration permits may be issued for a time period up to five (5) years. The owner of a dam and reservoir on the effective date of the law shall obtain his first registration permit in accordance with the height of his dam. For dam heights of thirty-five feet (35') to less than fifty feet (50'), fifty feet to seventy feet (50'-70'), and over seventy feet (70'+), the maximum time to obtain the first registration permit is respectively within nine (9) years, four (4) years, and two (2) years from the effective date of this section, August 13, 1981.

(3) Construction permits (see 10 CSR 22-1.020(8)) apply to the construction of a new dam and reservoir, or the alteration, enlargement, reduction, repair, or removal of a new or existing dam, reservoir or appurtenances. New dams are dams for which construction commences after the effective date of this section, August 13, 1981. For dams that were under construction on August 13, 1981, construction must be completed by August 13, 1987 or the owner will be required to obtain a construction permit. If completed prior to August 13, 1987, the owner will be required to obtain a registration permit as outlined in 10 CSR 22-2.020(2). A construction permit may be issued for any reasonable length time period required to complete construction and it may contain appropriate restrictions placed on the owner for construction and operation of the dam and reservoir during that period. At the conclusion of construction, a safety or registration permit shall be obtained by the owner.

(4) Safety permits (see 10 CSR 22-1.020(45)) apply to the operation of a dam and reservoir constructed pursuant to a construction permit. The safety permit is not a guarantee of the dam and reservoir's safety and does not alter the owner's liability; it is simply an operating permit. If a dam and reservoir were not subject to the provisions of the law when they were constructed but subsequently become subject to the provisions of the law, the owner shall obtain a registration permit, not a safety permit. Safety permits may be issued for a time period up to five (5) years, and they may contain appropriate conditions for the operation and safety of the dam and reservoir.

Auth: sections 236.400, 236.405, 236.415, 236.435, 236.440 and 236.465, RSMo (1986). Original rules filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985. Amended: Filed May 15, 1987, effective September 15, 1987.

10 CSR 22-2.030 Types of Dams and Reservoirs

PURPOSE: The purpose of this rule is to describe the two (2) fundamentally different types of dams and reservoirs that will be required to obtain permits from the Dam and Reservoir Safety Council.

(1) There are two (2) types of dams and reservoirs, conventional dams and reservoirs and industrial water retention dams and reservoirs. The two (2) types of dams and reservoirs are distinguished on the basis of their reservoir contents and the length of the time period during which active dam building occurs.

(2) Conventional dams and reservoirs (see 10 CSR 22-1.020(9)) are dams and reservoirs used for purposes other than tailings, slime, settling or other similar industrial water retention purposes. A conventional dam is constructed in one relatively continuous operation over a short time span (compared to the design life of the reservoir). Filling and use of the reservoir occurs after construction is completed.

(3) Industrial water retention dams and reservoirs (see 10 CSR 22-1.020(26)) are dams and reservoirs used for the purpose of storing solids and the water associated with the particular industrial process such as tailings, slime and other similar industrial materials. An industrial water retention dam may be constructed in phases and steps or continuously, over a long period of time (compared to the design life of the reservoir). Filling and use of the reservoir may occur during most phases of construction. An industrial water retention dam and reservoir in existence or under construction on the effective date of 10 CSR 22-2.020(2), August 13, 1981, shall obtain a registration permit which may include approval to make enlargements. The owner of any such dam and reservoir shall apply for and obtain new construction and/or registration permits for any modifications to that dam and reservoir other than enlargements covered by an existing permit. A construction permit is required and shall be obtained by the owner, for the initial construction phase of any new industrial water retention dam and reservoir built after the effective date of 10 CSR 22-2.020(3), August 13, 1981. Upon completion of the initial construction phase, the owner shall apply for a safety permit for the operation and enlargement of the new dam and reservoir.

Auth: sections 236.405, 236.415, 236.435, 236.440, and 236.465, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-2.040 Classes of Downstream Environment

PURPOSE: The purpose of this rule is to describe the three (3) environmental classes for the downstream environmental zone that will be used by the Dam and Reservoir Safety Council when considering permits.

(1) The downstream environment zone is the area downstream from a dam that would be affected by inundation in the event the dam failed. Inundation is defined as water, two feet (2') or more deep over the general level of the submerged ground affected outside the stream channel. Based on the content of the downstream environment zone, three (3) environmental classes are defined. They are: class I, which contains ten (10) or more permanent dwellings or any public building; class II, which contains one (1) to none (9) permanent dwellings, or one (1) or more campgrounds with permanent water, sewer and electrical services or one (1) or more industrial buildings; and class III, which is everything else.

(2) Spillway design standards are based on the environmental class of the downstream environment zone of a dam and reservoir. The standards become more stringent for lower environmental class numbers. If conditions change in the downstream environment zone and it becomes necessary to change the environmental class of the dam and reservoir, the owner must then meet the standards and criteria for the new environmental class of the dam and reservoir. A dam and reservoir may be in only one (1) environmental class at any given time.

(3) Inundation, the downstream environment zone and the associated environmental class are analyzed assuming the dam fails with the reservoir at the emergency spillway crest elevation or the dam crest elevation in the absence of an emergency spillway. If the spillway standards for class I are used, the failure analysis does not have to be performed. If a failure analysis is made, the contents of the downstream environment zone used to determine the environmental class are only the features that would be inundated by the flooding resulting from the dam failure.

Auth: sections 236.405, 236.415, 236.435, 236.440 and 236.465, RSMo (1986). Original rules filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-2.050 Issuing First Permit

PURPOSE: The purpose of this rule is to describe the procedure for issuing the first permit to a dam and reservoir owner for a particular dam and reservoir.

(1) A permit will be issued or a letter will be sent to the owner with comment within forty-five (45) days after the receipt of a properly prepared application or after the completion of any hearings or record period conducted by the council in connection with such application, whichever is later. The council, upon hearing the recommendations of the chief engineer, shall approve or deny the permit application.

(2) A permit will be issued if a complete and proper application has been submitted and the dam and reservoir comply with the law.

(A) A registration permit may be denied if it is determined that the owner has not complied with the experienced professional engineer's or agency engineer's inspection recommendations.

(B) A construction permit may be denied if there is insufficient information to determine that the proposed construction, alteration, enlargement, reduction or removal of a dam or reservoir would not endanger public safety, life or property.

(C) A safety permit may be denied if it is determined that there are violations of the construction permit or the law.

(D) If revisions have been made which vary substantially from the provisions of the construction permit, the owner must show that the revisions do not endanger public safety, life or property before a safety permit will be issued.

(3) Conditions contained in a construction permit shall include that the construction work must be under the responsible charge of an experienced professional engineer and that records be kept and made available as required by the chief engineer including, without limitation, for the foundation excavation and inspection and placement of backfill in the core trench. It is not necessary for the engineer in responsible charge to be on site continuously. During construction, the council or its del-

egate, or the chief engineer, may make periodic site inspections for the purpose of inspecting for and securing conformity of construction with the approved plans and specifications, and the owner shall, upon reasonable notice, permit such person entry upon its property to make such inspections. The owner may be required to perform, at their own expense, reasonable work or tests as are necessary to provide sufficient information to enable the council to determine that there is such conformity. Usually, such testing will be limited to verification of embankment compaction, concrete strengths and other similar requirements. It is expected that such tests will be required where the owner's inspection records are lacking.

(4) Any significant modifications from construction permit or approved plans makes the permit void and requires the owner to obtain a new permit. Significant modifications to the plans and specifications must be prepared by an experienced professional engineer. The council or its delegate will follow the same evaluation procedures for the modifications as used with issuance of the original construction permit. Special attention will be given to these modification requests to provide a quick decision.

(5) The owner of a dam and reservoir that is removed under a construction permit must notify the council or its delegate when this work is completed and in conformity with the provisions of the construction permit. The council or its delegate will then issue a final approval to relieve the owner of the requirement to have a permit upon a showing that the requirements of the law for removal have been satisfied.

(6) Approval by the council for a construction permit becomes invalid within one (1) year unless work on the construction has begun within that period, except that the owner may be excused from beginning work for such period of time that the work is prevented by flood, shortage of materials or regulation of government which cannot be met for reasons over which the owner has no control or other causes beyond the owner's control. The same applies to construction of approved modifications contained in the conditions of a registration or safety permit for industrial water retention dams unless the conditions specify a different time schedule.

Auth: sections 236.400, 236.405, 236.415, 236.435, 236.440 and 236.465, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-2.060 Issuing Permit Renewals

PURPOSE: The purpose of this rule is to describe the procedure for renewing a permit.

(1) The owner of a permitted dam and reservoir must apply for the renewal of the permit not less than sixty (60) days prior to expiration of that permit. Before any permit may be renewed, the chief engineer must determine that the dam and reservoir are essentially as described in the latest permit and approved plans; they satisfy the law; and that no inspection conducted in connection with the permit renewal reveals any defect which would threaten public safety, life or property. The council or its delegate will issue another permit within forty-five (45) days of the receipt of a complete and proper application unless it is determined that the dam and reservoir are not as described in the latest permit and approved plans; not properly maintained; do not satisfy the law; or that the defects are not corrected.

(2) The council may require the owner to furnish a certification by an experienced professional engineer or an agency engineer that the dam and reservoir are as described in the latest permit and approved plans; are properly maintained, satisfy the law; and have all the defects corrected.

Auth: sections 236.405, 236.415, 236.440 and 236.465, RSMO (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-2.080 Revoking Permit

PURPOSE: The purpose of this rule is to describe the reasons for revoking a permit.

(1) Approval of the council or its delegate, the chief engineer, shall be obtained for modifications that substantially alter or adversely affect the safety or stability of the dam or reservoir. Such modifications, without the approval of the council or its delegate, the chief engineer, are cause for suspension or revocation of any permit. It the chief engineer finds that the condition of the dam and reservoir has deteriorated substantially from those conditions present when the permit was issued, or that has defects which adversely affect the safety or sta-

bility of the dam and reservoir or threatens public safety, life or property, he shall suspend or revoke the permit. It a permit is suspended or revoked, the dam owner will be in violation of the law and may be subject to prosecution for a misdemeanor.

(2) If the chief engineer determines that a dam or reservoir constitutes a threat to public safety, life or property, he may order its removal or take any other actions necessary to reduce or eliminate such threat. Failure of a dam owner to alter or remove his dam and reservoir, as directed, when it is found to be a threat to public safety, life or property will result in revocation of the permit and, if necessary, removal of the dam or any other action necessary to reduce or eliminate the threat to public safety, life or property by the state at the owner's expense.

Auth: sections 236.405, 236.415, 236.445, 236.495 and 236.500, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-2.090 Transferring Permit

PURPOSE: The purpose of this rule is to describe the procedure for transferring a permit with ownership changes.

(1) Permits issued pursuant to 10 CSR 22-2.050 and 10 CSR 22-2.060 are transferable only as provided in section 236.460 RSMo (1986). If ownership or other transfer of interest in the dam and reservoir changes, the former owner must notify the chief engineer of the sale or transfer and the permit will be transferred to the new owner after determination that such transfer will not endanger the public safety, life, property, the dam or reservoir. The permit holder of record will be held responsible for maintaining compliance with these rules and standards. If the former owner does not have the permit transferred, the new owner may submit the appropriate application and documents necessary to obtain a new permit. The new owner must, in this case, also show proof of ownership. The old owner's responsibilities of ownership under the law will not be extinguished until the permit is transferred to an eligible owner. Nothing in these regulations shall be construed to eliminate the liability of the previous owner for injuries caused by a dam failure, nor a new operator who has not obtained a permit nor had an existing permit transferred to his name.

Auth: sections 236.405, 236.415, and 236.460, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-2.100 Appeal of Action on Permits

PURPOSE: The purpose of this rule is to describe the procedure for appealing the results of any action taken with regard to a permit.

(1) Permits revoked or denied are subject to council appeal. All parties shall be afforded an opportunity for hearing before the council for review of denial or revocations decisions, if request is made within thirty (30) days after notice is served personally or by certified or registered mail upon such parties or their agents. Except for emergency action, further legal action shall not be taken until after such hearing and council decision.

(2) The record of hearing shall include all written testimony, data, records, etc. as well as all oral proceedings recorded stenographically or by such other means that will preserve the testimony. Rules of discovery, evidence and privilege as applied in civil cases in the circuit courts shall be followed.

(3) A final decision will be in writing, and the party or their agents will be notified personally or by registered or certified mail of the final decision. A copy of any opinion in support of this decision will be furnished upon request. Such decisions are subject to judicial review pursuant to provisions of section 236.480, RSMo (1986).

Auth: sections 236.405, 236.415, 236.425, 236.440, 236.445, 236.470 and 236.480, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

TITLE 10 – DEPARTMENT OF NATURAL RESOURCES
DIVISION 22 – DAM AND RESERVOIR SAFETY COUNCIL

CHAPTER 3 – PERMIT REQUIREMENTS

10 CSR 22-3.010 General Information

PURPOSE: The purpose of this rule is to provide general information about permit requirements.

(1) Requirements for existing or proposed dams and reservoirs must allow for variations in conditions and materials from site to site. Therefore, this rule and rules 10 CSR 22-3.020 to 10 CSR 22-3.050 describe the minimum general requirements which are consistent with current engineering, geologic, construction, operation and maintenance practices, necessary to obtain permits from the Dam and Reservoir Safety Council.

(2) These rules are not intended to define the only requirements for a dam and reservoir to comply with the law, or the only engineering, geologic and construction practices to be used in detailed site investigation or in the specific design and construction of individual dams. The detailed and specific information that outlines current and prudent engineering, geologic and construction practices is available in technical literature. Determinations by the Dam and Reservoir Safety Council, after hearing the recommendations of the chief engineer of the acceptability of a design and adequacy of plans, specifications and construction must, by necessity, be made on a case by case basis. Therefore, it is recommended that applicants unfamiliar with the way these rules are applied contact the council or the chief engineer prior to commencing extensive work or plan development.

(3) Adherence to the law does not guarantee the safety of any dam or reservoir or relieve the owner of any liability in the event of dam failure.

(4) A permit application form along with a copy of the laws, rules, standards, and guidelines relating to dam and reservoir safety can be obtained free from the Department of Natural Resources, Geological Survey and Resource Assessment Division, Dam Safety Program, PO Box 250, Rolla, MO 65402-0250. Persons seeking this and/or other information on dams in Missouri should address their inquiry to the chief engineer.

Auth: sections 236.400, 236.405, 236.415, 236.435, 236.440 and 236.465, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-3.020 General Requirements

PURPOSE: The purpose of this rule is to itemize the basic requirements and standards that apply to all permits.

(1) The permit application must contain information required by the council and the chief engineer including, but not limited to, the following information: type of permit being applied for; name of owners; mailing address of owners; telephone number(s) of owners; name of dam; name of reservoir; coordinate location of the dam centerline at the maximum section; purpose or use of dam and reservoir; name, address and telephone number of the experienced professional engineer or agency engineer who has provided or will provide required technical assistance; and the downstream environment zone environmental class for the dam and reservoir. The owners must complete applicable investigations required in 10 CSR 22-3.020 to 10 CSR 22-3.050 before filing a permit application. All permit applications must be filed with the chief engineer at the address listed in 10 CSR 22-3.010 (4).

(2) The owner must provide a determination of an environmental class for each dam and reservoir. The method, data, and assumptions used by the owner to determine environmental class shall conform to practices reputable and in current use in the engineering, geologic and construction profession or the chief engineer may reject the owner's classification. If an owner chooses not to have this done by an experienced professional engineer or an agency engineer, the chief engineer will assign the dam and reservoir to environmental class I or he may assign the dam and reservoir to the appro-

priate environmental class if he has justification to do so.

(3) The anticipated consequences of a dam failure with respect to public safety, life and property damage are important considerations in establishing acceptable methods for specific investigations and sites. Methods used in exploration, design, construction and maintenance must be in accordance with good engineering practices reputable and in current use in the engineering, geologic and construction professions.

(4) When the owner is applying for a construction permit, the required design factors of safety for slope stability for earth and rock conventional dams which are given in Table 1 shall be met. The required design factors of safety for concrete conventional dams are given in Table 2. The required design factors of safety for slope stability for industrial water retention dams are given in Table 3. Owners shall meet these requirements in the design of new dams prior to the issuance of the permit. Owners shall also meet these requirements when substantial changes are proposed to the height or slope of an existing conventional dam or structure prior to the issuance of the construction permit. (see following tables)

(5) For new dams constructed wholly or partially of cohesionless materials (such as sands and silts) or having a foundation of cohesionless materials, earthquake loading may result in the build-up of pore water pressures and a loss of strength. Engineers shall take this pore pressure increase and loss of strength into account when performing their stability analysis, but the degree to which liquefaction may affect the factor of safety for slope stability shall be left up to the engineer's best judgement. Bedrock accelerations and earthquake intensities are listed in Table 4.

(6) New dams constructed wholly of cohesive materials (such as clays) and having a foundation of cohesive materials or bedrock, can be expected to withstand significant earthquake shaking if it can be shown that other required design factors of safety for slope stability are met. Therefore, only new dams located in Bollinger, Butler, Cape Girardeau, Dunklin, Mississippi, New Madrid, Pemiscot, Ripley, Scott, Stoddard and Wayne counties must meet the requirements for slope stability during earthquake loading while dams located in other counties do not unless 10 CSR 22-3.020(5) applies to them. Bedrock accelerations and earthquake intensities are listed in Table 4.

(7) The required spillway design flood, which shall allow for flood storage in the reservoir, is to be derived by using the precipitation values given in Table 5 and shall apply to both new and existing dams.

Auth: sections 236.400, 236.405, 236.435, 236.440 and 236.465, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-3.030 Registration Permit Requirements

PURPOSE: The purpose of this rule is to itemize the requirements for a registration permit.

(1) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020(1),(2),(3) and (7), the registration permit application for a conventional dam and reservoir must include certification by an experienced professional engineer or an agency engineer that the dam and reservoir have been inspected in accordance with the law and that the owner has complied with the engineer's recommendations to correct observed defects and an inspection report, as required by the law. The engineer must further show that the spillway can safely pass the spillway design flood derived from Table 5 and submit a report describing the correction of all observed defects and the description of an operation and maintenance program to be followed while the registration permit is in effect.

(A) The inspection of a dam and reservoir for a registration permit is intended to detect observable defects. The procedure to determine observable defects normally will be a surface examination by an experienced professional engineer or an agency engineer. The inspection must include all surface examinations necessary to determine if observable defects exist that affect the stability of the dam and reservoir or the adequacy of the spillway. Judgement of the structural stability and an evaluation of the spillway capacity must be made. Judgement shall be based upon the engineer's experience, training and knowledge of similar dams and in accordance with practices reputable and in current use in the engineering, geologic and construction professions.

1. Observed defects which may require correction, evaluated on the basis of current engineer-

TABLE 1

Required Design Factors of Safety for Slope Stability
Earth and Rock Conventional Dams

Loading Condition	Factor of Safety
End of construction, full reservoir*	1.4
Steady seepage, full reservoir*	1.5
Steady seepage, maximum reservoir*	1.3
Sudden drawdown, from full to empty reservoir (if applicable)	1.2
Earthquake***, steady seepage, full reservoir*	1.0

* Full reservoir means water level is at the water storage elevation

** Maximum reservoir means water level is at maximum water level attained during the spillway design flood or at the dam crest elevation, whichever is lower.

*** Earthquake loading will vary according to dam location in relation to seismic source zones and downstream environmental zones. See Table 4.

TABLE 2

Required Design Factors of Safety
Concrete Conventional Dams

Failure Mode	Loading Condition	Factor of Safety
Overturning	full reservoir*	1.5
	maximum reservoir**	1.3
Sliding	full reservoir*	1.5
	maximum reservoir**	1.3
Structural integrity	full reservoir*	1.5
	maximum reservoir**	1.3
Earthquake*** - any mode	full or maximum reservoir* & **	1.0

* Full reservoir means water level is at the water storage elevation.

** Maximum reservoir means water level is at maximum level attained during the spillway design flood.

*** Earthquake loading will vary according to dam location in relation to seismic source zones and downstream environmental zones. See Table 4.

TABLE 3

Required Design Factors of Safety for Slope Stability
Industrial Water Retention Dams

Loading Condition	Factor of Safety
Starter dam, end of construction, full reservoir*	1.4
Any other stage of construction, full reservoir*, steady seepage	1.3
Any other stage of construction, maximum reservoir**, steady seepage	1.0
Completed dam, full reservoir*, steady seepage	1.5
Completed dam, maximum reservoir**, steady seepage	1.3
Earthquake***, steady seepage, full reservoir*	1.0

* Full reservoir means water level is at the water storage elevation.

** Maximum reservoir means water level is at maximum water level attained during the spillway design flood or at the dam crest elevation, whichever is lower.

*** Earthquake loading will vary according to dam location in relation to seismic source zones and downstream environmental zones. See Table 4.

TABLE 4

Required Design Acceleration for Earthquake Design

Dam Type	Stage of Construction	Special Descriptions	Environmental Class I	II	III
Conventional or Industrial	Completed	New dams less than 50 feet in height	.75PMA*	.5PMA*	.25PMA*
		New dams greater than 50 feet in height**	.75PMA*	.5PMA*	.4PMA*
Industrial	Starter Dam	New Dams**	.5PMA*	.2PMA*	.1PMA*
	After starter dam is finished and before final dam is completed	New Dams**	.75PMA*	.5PMA*	.2PMA*

Zone:	A	B	C	D	E	F
PMA*:	0.31g	0.28g	0.26g	0.23g	0.20g	0.17g
Intensity***:	IX-X	IX	VIII-IX	VIII	VII-VIII	VII

* PMA is Probable Maximum Acceleration of bedrock which is determined by the zones as a fraction of the acceleration of gravity (g-32.2fps^2) for six zones in Missouri (See 10 CSR 22-1.010(40)).

** See 10 CSR 22-2.020(3) for clarification.

*** Modified Mercalli Intensity.

TABLE 4 (cont.)

ZONE A
Dunklin
Mississippi
New Madrid
Pemiscot

ZONE B
Bollinger
Butler
Cape Girardeau
Ripley
Scott
Stoddard
Wayne

ZONE C
Carter
Howell
Iron
Madison
Oregon
Perry
Reynolds
St. Francois
Ste. Genevieve
Shannon

ZONE D
Crawford
Dent
Douglas
Franklin
Jefferson
Ozark
Phelps
Pulaski
St. Louis
St. Louis City
Taney
Texas
Washington
Wright

ZONE E
Audrain
Barry
Barton
Bates
Benton
Boone
Caldwell
Callaway
Camden
Carroll
Cass
Cedar
Chariton
Christian
Clark
Cole
Cooper
Dade
Dallas
Gasconade
Greene
Henry
Hickory
Howard
Jackson
Jasper
Johnson
Knox
Laclede
Lafayette
Lawrence
Lewis
Lincoln
Linn
Livingston
McDonald
Macon
Maries
Marion
Miller
Moniteau
Monroe
Montgomery
Morgan
Newton
Osage
Pettis
Pike
Polk
Ralls
Randolph
Ray
St. Charles
St. Clair
Saline
Scotland
Shelby
Stone
Vernon
Warren
Webster

ZONE F
Adair
Andrew
Atchison
Buchanan
Clay
Clinton
Daviess
Dekalb
Gentry
Grundy
Harrison
Holt
Mercer
Nodaway
Platte
Putnam
Schuyler
Sullivan
Worth

TABLE 5

Required Spillway Design Flood Precipitation Values

Dam Type	Stage of Construction	Special Descriptions	Environmental Class I	Environmental Class II	Environmental Class III
Conventional or Industrial	Completed	Any existing dam**	.75PMP*	.5PMP*	100 Yr****
		New dams less than 50 feet in height**	.75PMP*	.5PMP*	100 Yr****
		New dams greater than 50 feet in height**	.75PMP*	.5PMP*	100 Yr****
Industrial	Starter Dam	Any	.5PMP*	.2PMP*	.1PMP*
	After starter dam is finished and before final dam is completed	Any	.75PMP*	.5PMP*	.2PMP*

* PMP is Probable Maximum Precipitation.
** Existing dam means a dam which was completed by August 13, 1981 or which was started prior to August 13, 1981 and completed by August 13, 1987.
*** See 10 CSR 22-2.020(3) for clarification.
**** 100 Yr is the 100-year frequency rainfall event.

ing, geologic and construction practices, include but are not limited to: slides; slopes as steep as or steeper than those on similar types of dams and constructed of similar materials which have experienced slope stability problems; piping of fines; seepage that exits in an uncontrolled fashion on the downstream slope of or from the downstream foundation of the dam; unusual zones of softness and irregular settlement; erosion on the upstream or downstream slope of the dam; spillways that are calculated to be inadequate for the design flood; spillways that are eroded or otherwise in poor condition; and cracks in the embankment or structure.

2. Observed defects that are in an advanced state of deterioration must be immediately reported by the inspecting engineer to the owner and to the chief engineer.

(B) Proper maintenance and operation of a dam and reservoir are critical to the continuing safety of a dam and reservoir and to public safety, life and property. A maintenance program shall be required and shall include the following items: erosion control on the embankment; monitoring emergency spillway flow rates; vegetation control; spillway maintenance; emergency action plans; maintenance and monitoring of seepage observation devices, if any; and maintenance and monitoring of instruments used, if any, to observe the stability of the dam.

(C) Visits for the purpose of observation of maintenance and operation may be made by the council, the chief engineer or a member of the chief engineer's staff. Such visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property no such notice shall be required, and inspection may be at any time. Owners shall permit entry to its property for such persons to perform such inspections.

(D) The application need not state, nor is it necessary to show, that the dam is a safe dam. The intent of the registration permit is to show that the dam is performing adequately and that there are no observable indications that the dam is unsafe.

(2) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020(1),(2),(3), and (7), the registration permit application for an industrial water retention dam and reservoir shall include certification by an experienced professional engineer or an agency engineer that the dam and reservoir have been inspected in accordance with the law and that the owner has complied with the engineer's recommendations to correct observed defects and an inspection report, as required by the law. The engineer must further show that the spillway can safely pass the spillway design flood derived from Table 5 and submit a report describing the correction of any observed defects, the operation and maintenance program to be made a part of the registration permit, and the phased, stepped, and/or continuous construction of the dam.

(A) The inspection of an industrial water retention dam and reservoir for a registration permit is intended to detect observable defects. The procedure to determine observable defects normally will be a surface examination by an experienced professional engineer or an agency engineer. The inspection must include all surface examinations necessary to determine if observable defects exist that affect the stability of the dam and reservoir or the adequacy of the spillway. Judgement of the structural ability and an evaluation of the spillway capacity must be made. Judgement shall be based upon the engineer's experience, training, and knowledge of similar dams and in accordance with practices reputable and in current use in the engineering, geologic and construction professions.

1. Observed defects which may require correction, evaluated on the basis of current engineering, geologic and construction practices, include but are not limited to: slides, slopes as steep as or steeper than those on similar types of dams and constructed of similar materials which have experienced slope stability problems; piping of fines; seepage that exits in an uncontrolled fashion on the downstream slope of or from the downstream foundation of the dam; unusual zones of softness and irregular settlement; erosion on the upstream or downstream slope of the dam; spillways that are calculated to be inadequate for the design flood; spillways that are eroded or otherwise in poor condition; and cracks in the embankment or structure.

2. Observed defects that are in an advanced state of deterioration must be immediately reported by the inspecting engineer to the owner and to the chief engineer.

(B) Proper maintenance and operation of a dam and reservoir are critical to the continuing safety of a dam and reservoir and the protection of public safety, life and property. A maintenance and operation program shall be required and shall include the following items: erosion control on the embankment; monitoring of storm runoff; vegetation control spillway maintenance; emergency action plans; maintenance and monitoring of seepage observation devices, if any; and maintenance and monitoring of instruments used, if any, to observe the stability of the dam.

(C) The council or chief engineer may require the owner to submit a report describing the phased, stepped and/or continuous construction of an industrial water retention dam and reservoir, containing information on the materials used, method of transport and placement of materials, the sequence and placement location of materials, spillway changes to be made, the anticipated final dimensions and configuration of the dam and the name, address and telephone number of the person(s) in responsible charge of this work.

(D) Visits for the purpose of inspecting during construction or enlargement or observation of maintenance and operation may be made by the council, the chief engineer or a member of the chief engineer's staff. Such visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, no such notice shall be required, and inspection may be made at any time. Owners shall permit entry to its property for such persons to perform such inspection.

(E) It shall not be necessary for the owner to retain an experienced professional engineer or an agency engineer continuously during the entire permit period unless there is modification(s) in the construction method described in the permit application. However, personnel with adequate supervision and training in methods of safe construction, maintenance and operation of dams must be provided to insure that the construction, maintenance and operation of the dam and reservoir are carried out as described.

(F) The registration permit will be the only permit required for an industrial water retention dam and reservoir that was in existence prior to the effective date listed in 10 CSR 22-2.020(2) unless it is to be reduced and removed. If the dam or reservoir is to be reduced or removed, a construction permit will be required. Other changes will require the owner to obtain a new registration permit.

(G) The application need not state, nor is it necessary to show, that the dam is a safe dam. The intent of the registration permit is to show that the dam is performing adequately and that there are no readily observable indications that the dam is unsafe, and that phased, stepped and/or continuous construction of the dam will meet the requirements of the law.

Auth: sections 236.400, 236.405, 236.415, 236.420, 236.425, 236.440 and 236.465, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-3.040 Construction Permit Requirements

PURPOSE: The purpose of this rule is to itemize the requirements for a construction permit.

(1) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020, the construction permit application for a conventional dam and reservoir shall be prepared by or under the direction of and certified by an experienced professional engineer and shall be in accordance with practices reputable and appropriate in the engineering, geologic and construction professions.

(A) The following requirements shall apply to, and the following information shall be provided by the owner:

1. Up-to-date topographic map(s) showing the location of the proposed or existing dam, the upstream watershed, the reservoir, and the downstream environment zone. The topographic map(s) of the project area must be at a scale appropriate to the size of the project area. An up-to-date US Geological Survey topographic map is considered a minimum;

2. Exploration records and results including the location of all exploration, especially in the area of the core trench, the method(s) used to explore the site, a record of what was found, the method(s) used to obtain samples and the number of samples taken;

3. Testing records and results including information on the care and treatment of samples, types of tests performed on samples or in situ, reference(s) to or the procedures used in testing, and the test results. Physical and mechanical properties of foundation and construction materials must include the information source for these values especially if they are not the results of testing;

4. The geotechnical design procedures or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. This shall include all assumptions made. The geotechnical procedure(s) or design results shall include the minimum computed factors of safety and they must meet or exceed the required design factors of safety (see 10 CSR 22-3.020(4)). The geotechnical design information shall be presented for the foundation, core trench, and dam embankment. Earthquake loading must be analyzed as outlined in 10 CSR 22-3.020(5) and (6);

5. The structural design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. Design results for concrete dams and concrete structures appurtenant to embankment dams shall provide for and show an adequate factor of safety for normal and maximum loading conditions of compression, tension, shear, torsion, buckling, sliding, and overturning;

6. Hydrologic information used to evaluate the watershed, reservoir, spillway, and downstream environment zone including the watershed area, rainfall rate and duration, antecedent moisture conditions, time of concentration, area capacity curves, description of spillway elevation(s), type(s) dimensions, locations, cross-sections and profiles, dam crest elevation and the downstream valley cross-sections;

7. The hydrologic/hydraulic design procedure(s) or method(s) used shall be identified and referenced or described so that they may be reviewed and their applicability verified. This shall include all assumptions made. The hydrologic/hydraulic procedure(s) or design results shall include the reservoir inflow hydrograph, the reservoir outflow hydrograph, the spillway discharge capacity, the freeboard at the maximum water storage elevation and the environmental class of the dam. The dam shall be capable of safely containing or discharging the required design flood (see 10 CSR 22-3.020(7)).

8. Location and design of diversion channels or other structures to control stream flow during or after construction shall be provided if failure of these channels or other structures would affect hydrologic conditions of the dam. Stream diversion systems used during construction shall be designed to provide protection to the dam and the safety of the public.

9. Construction control and inspection procedures shall be used during the construction of a new dam and reservoir or modification of an existing dam and reservoir. Construction control and inspection procedures should include compaction testing and density testing;

10. Procedures shall be used for record keeping and monitoring throughout the construction or modification process to provide information about any construction progress and conditions that may cause difficulties during construction;

11. The location of and protective measures used in conjunction with all drain lines, sewer lines, utilities or other structures that pass through or under the dam;

12. Topographic surveys showing the location of baselines, centerlines, and other horizontal and vertical control points sufficiently accurate to locate the proposed construction and to define the volume of storage in the reservoir.

13. Two (2) sets of plans and specifications including:

A. Graphic scales shall be provided for all scaled drawings;

B. The title, which shall be identical on the plans and the specifications, shall include: the name of the dam; the name of the owner; whether the work shows an existing dam, a proposed dam or an enlargement, repair or alteration of the dam or reservoir; the county or counties the dam and reservoir are in; the location of the dam by quarter section, section, township, and range or by geodetic coordinates; and each sheet shall have in an appropriate title block the name of the dam as well as the sheet number in relation to the total, e.g. sheet 1 of 12; and

C. Certifications by the experienced professional engineer and the owner shall be placed near the lower right hand corner of the title sheet (first sheet) of the drawings. The certifications shall be similar to those presented in figures 1 and 2 (see figs. 1 and 2).

14. If a construction permit is requested to convert a dam to a retaining or retarding structure, the procedure to be followed in making the conversion shall be described by the owner; and

15. The procedures set up for regular inspection by the owner. The owner shall develop an emergency action plan, inspect his dam regularly and as necessary to protect public safety, life and property. A list of items to be inspected, a time schedule for these inspections and a form for reporting the results shall be established.

(B) The council or chief engineer may require the following action and information from the owner:

1. Procedures set up to provide regular maintenance and minor repairs to the dam and reservoir after construction and to continue or start record keeping and monitoring work so that the dam and reservoir are maintained in a safe condition and a complete history of its performance is available;

2. Location and types of instrumentation; drainage and/or seepage control facilities. Monitoring equipment and drainage control facilities are recommended for all dams and reservoirs; however, depending on conditions, they may be mandatory items if necessary to accomplish the purposes of the law;

3. The downstream environment zone warning procedure to be used if dam failure is a threat. A downstream environment zone warning system is recommended for all dams and reservoirs; however, depending on conditions, it may be necessary to accomplish the purposes of the law. This would consist of the current name(s) of the dam and reservoir owner's representative(s) responsible for giving notification of a threat and the current phone numbers of appropriate local police and other persons having emergency assistance authority;

4. Upstream slope protection from wave action; and

5. Additional actions or information as required to protect public safety, life and property and to accomplish the purposes of the law.

(C) Visits for the purpose of inspecting during or after construction or observation of operation and maintenance may be made by the council, the chief engineer or a member of the chief engineer's staff. Such visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, no such notice shall be required and inspection may be made at any time. Owner shall permit entry to their property for such persons to perform such inspections.

(2) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020, the construction permit application for an industrial water retention dam and reservoir shall be prepared by or under the direction of and certified by an experienced professional engineer and shall be in accordance with practices reputable and appropriate in the engineering, geologic and construction professions.

(A) The engineer who plans and designs an industrial water retention dam and reservoir or its modification shall assess the sequence, timing, method of placement and stability control program during construction from the beginning of the starter dam or modification through the life of the structure and after operation ceases or until the dam and reservoir no longer need a permit.

(B) Adequate records, as required by good practices in the geologic and engineering professions, shall be kept and made available to the council or chief engineer for the construction, maintenance, and operation procedures. Adequate instrumentation and monitoring of seepage water shall be provided where necessary. Any significant settling or movement in the foundation of the dam should be measured if possible. Trained personnel and adequate supervision shall be provided to insure the construction and operation of the dam and reservoir are carried out to specifications.

FIGURE 1

Certification by Experienced Professional Engineer

I hereby certify that these plans for the (insert the correct word or words choosing from: existing, construction of the, repair of the, enlargement of the, or alteration of the) _____ (Name of Dam) Dam were prepared by me (or under my direct supervision) for the owners thereof.

_____
Firm Name

_____
Registered Engineer

FIGURE 2

Certification by Owner

I, _____, owner, whose Post Office Address is

_____, Zip _____, do hereby accept and approve these plans.

_____
Owner

(C) The following requirements shall apply to, and the following information shall be provided by the owner:

1. A description of the system used to deposit tailings on the dam;

2. Up-to-date topographic map(s) showing the location of the proposed dam, the upstream watershed, the reservoir and the downstream environment zone. The topographic map(s) of the project area must be at a scale appropriate to the size of the project area. An up-to-date U.S. Geological Survey topographic map is considered a minimum;

3. The location(s) of surface and underground mine workings if these workings would cause, would contribute to the cause, or would be affected in the event of failure;

4. Exploration records and results including the location of all exploration, especially in the area of the core trench, the method(s) used to explore the site, a record of what was found, the method(s) used to obtain samples and the number of samples taken;

5. Testing records and results including information on the care and treatment of samples, types of tests performed on samples or in situ, reference(s) to or the procedures used in testing, and the test results. Physical and mechanical properties of foundation and construction materials must include the information source for these values especially if they are not the results of testing;

6. The geotechnical design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. This shall include all assumptions made. The geotechnical procedure(s) or design results shall include the minimum computed factors of safety and they must meet or exceed the required design factors of safety (see 10 CSR 22-3.020(4)). The geotechnical design information shall be presented for the foundation core trench and dam embankment. Earthquake loading must be analyzed as outlined in 10 CSR 22-3.020(5) and (6);

7. Type and physical properties of the liquid and solid materials to be used in construction of the dam and contained in the reservoir;

8. The changes created in the downstream environment zone as the dam and reservoir become incrementally larger;

9. The embankment changes and new factors of safety for stability as the dam and reservoir become incrementally larger;

10. If a starter dam is used, whether it will be pervious or impervious;

11. The expected crest elevation, dam configuration, spillway elevation, and the size and configuration of each successive stage of the dam shall be included;

12. Anticipated storage volume of solid or semi-solid materials and of liquids at the completion of the dam;

13. The structural design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. Design results for concrete dams and concrete structures appurtenant to embankment dams shall provide for and show an adequate factor of safety for normal and maximum loading conditions of compression, tension, shear, torsion, buckling, sliding and overturning;

14. Hydrologic information used to evaluate the watershed, reservoir, spillway, and downstream environment zone including the watershed area, rainfall rate and duration, antecedent moisture conditions, time of concentration, area capacity curves, description of spillway elevation(s), type(s), dimensions, locations, cross-sections and profiles, dam crest elevation, and the downstream valley cross-sections;

15. Hydrologic/hydraulic design procedure(s) or method(s) used shall be identified and referenced or described so that they may be reviewed and their applicability verified. This shall include all assumptions made. The hydrologic/hydraulic procedure(s) or design results shall include the reservoir inflow hydrograph, the reservoir outflow hydrograph, the spillway discharge capacity, the freeboard at the maximum water storage elevation and the environmental class of the dam. The dam shall be capable of safely containing or discharging the required design flood (see 10 CSR 22-3.020(7)).

16. The hydrologic changes, the spillway alterations proposed and the freeboard changes as the dam becomes incrementally larger;

17. Location and design of diversion channels or other structures to control stream flow during or after construction shall be provided if failure of these channels or other structures would affect the stability or hydrologic conditions of the dam. Stream diversion systems used during construction shall be designed to provide protection to the dam and to protect public safety, life and property;

18. Location and design of any diversion channels or other structures to control runoff or reclaimed water;

19. Construction control and inspection procedures shall be determined by the engineer and used during the construction of a new dam and reservoir or modification of an existing dam and reservoir. Construction control and inspection procedures shall include compaction testing, density testing, and any other quality control measures used to insure compliance with the construction specifications;

20. Procedures shall be used for record keeping and monitoring throughout the construction, enlargement or modification process to provide information about construction progress and any conditions that may cause difficulties during construction.

21. The location of and protective measures used in conjunction with all drain lines, sewer lines, utilities or other structures that pass through or under the dam;

22. Topographic surveys showing the location of baselines, centerlines and other horizontal and vertical control points sufficiently accurate to locate the proposed construction and to define the volume of storage in the reservoir at each planned stage of construction.

23. Two (2) sets of plans and specifications including:

A. Graphic scales shall be provided for all scaled drawings;

B. The title, which shall be identical on the plans and the specifications shall include: the name of the owner; whether the work shows an existing dam, a proposed dam, or an enlargement, repair or alteration of the dam and reservoir; the county or counties the dam and reservoir are in; the location of the dam by quarter section, section, township and range or by geodetic coordinates; and each sheet shall have in an appropriate title block the name of the dam as well as the sheet number in relation to the total, e.g., sheet 1 of 12; and

C. Certification by the experienced professional engineer and the owner shall be placed near the lower right hand corner of the title sheet (first sheet) of the drawings. The certifications shall be similar to those presented in figures 1 and 2 (see figs. 1 and 2 preceding).

24. If a construction permit is requested to convert a dam to a retaining or retarding structure, the procedure to be followed in making the conversion shall be described by the owner; and

25. The procedure set up for regular inspection by the owner. The owner shall develop an emergency action plan, inspect his dam and reservoir regularly and as necessary to protect public safety, life and property. A list of items to be inspected, a time schedule for these inspections and a form for reporting the results shall be established by the council or chief engineer. Items that shall receive maintenance to and/or inspections on a daily basis during periods of active dam enlargement include: the spigots or cyclones; the decant lines; the position of the water pool in relation to the spillway, decant intake and crest of the tailings dam; drain lines checked for quantity of water and sediment; the embankment observed for visual defects such as slides or significant seepage changes; the spillway shall be checked to verify that it has not become blocked.

(D) The council or chief engineer may require the following action and information from the owner:

1. Procedures set up to provide regular maintenance and minor repairs to the dam and reservoir during construction and enlargement so that the dam and reservoir are maintained in a safe condition and a complete history of its performance is available;

2. Location and types of instrumentation, drainage, and/or seepage control facilities. Monitoring equipment and drainage and seepage control facilities are recommended for all dams and reservoirs; however, depending on conditions, they may be mandatory items if necessary to accomplish the purposes of the law;

3. The downstream environment zone warning procedure to be used if dam failure is a threat. A downstream environment zone warning system is recommended for all dams and reservoirs; however, depending on conditions, it may be necessary to accomplish the purposes of the law. This would consist of the current name(s) of the dam and reservoir owners representative(s) responsible for giving notification of a threat of failure and the current phone numbers of appropriate local police and other persons having emergency assistance authority;

4. Upstream slope protection from wave action; and

5. Additional actions or information as required to protect public safety, life and property and to accomplish the purposes of the law.

(E) Visits for the purpose of inspecting during or after construction or observation of operation and maintenance may be made by the council, the chief engineer, or a member of the chief engineer's staff. Such visits will be at any reasonable time following reasonable notice, except that in the case of an

emergency threatening public safety, life or property, no such notice shall be required and inspection may be made at any time. Owners shall permit entry to their property for such persons to perform such inspections.

(F) Drawings to show changes shall be submitted when such changes are made to the original plans including, without limitation, changes in incremental dam crest heights, spillway locations, and cross-sections.

Auth: sections 236.400, 236.405, 236.415, 236.420, 236.425, 236.435, 236.440 and 236.465, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

10 CSR 22-3.050 Safety Permit Requirements

PURPOSE: The purpose of this rule is to itemize the requirements for a safety permit.

(1) In addition the basic requirements for all permits listed in 10 CSR 22-3.020, the safety permit application for a conventional dam and reservoir shall include:

(A) Notification of the completion of construction and application for the first safety permit for the dam and reservoir shall be provided by the owner. The experienced professional engineer or agency engineer who was in responsible charge of the construction work shall certify that the construction was substantially in accordance with the approved plans and specifications. If revisions have been made which vary considerably from the provisions of the construction permit, it must be shown that the revisions do not endanger public safety, life or property. This subsection shall not be construed to excuse any person from the requirement to notify the council or chief engineer of modifications or revisions prior to commencing such actions and to obtain the required permits or authorization therefore;

(B) Notification of completion shall be within two (2) month's time after completion of construction; and

(C) As built drawings shall be submitted.

(2) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020, the application for a safety permit for an industrial water retention dam and reservoir shall include:

(A) Notification of completion of the starter dam or the initial phase of construction shall be prepared by or under the supervision of an experienced professional engineer in accordance with the provisions of the construction permit;

(B) Notification of the completion of construction and application for the first safety permit for the dam and reservoir shall be provided by the owner or the experienced professional engineer who was in responsible charge of the construction work. The engineer shall certify that the construction was substantially in accordance with the approved plans and specifications. If revisions have been made which vary considerably from the provisions of the construction permit, it must be shown that the revisions do not endanger public safety, life or property. This subsection shall not be construed to excuse any person from the requirement to notify the council or chief engineer of modifications or revisions prior to commencing such actions and to obtain the required permits or authorization therefore;

(C) Notification of completion shall be within two (2) month's time after completion of construction; and

(D) As built drawings shall be submitted.

(3) Visits for the purpose of observation of operation and maintenance procedures may be made by the council, the chief engineer or member of their staff. Such visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, no such notice shall be required, and inspection may be made at any time. Owners shall permit entry to their property for such persons to perform such inspections.

Auth: sections 236.400, 236.405, 236.415, 236.420, 236.425, 235.440, and 236.465, RSMo (1986). Original rule filed April 14, 1981, effective August 13, 1981. Amended: Filed June 14, 1984, effective January 1, 1985.

TITLE 10 – DEPARTMENT OF NATURAL RESOURCES
DIVISION 22 – DAM AND RESERVOIR SAFETY COUNCIL

CHAPTER 4 – ACTION TAKEN BY COUNCIL AND CHIEF ENGINEER

10 CSR 22-4.010 Emergency Action

PURPOSE: The purpose of this rule is to define the way emergency action is taken.

(1) In performing his duties, the chief engineer shall determine by inspection whether a dam or reservoir constitutes a threat to public safety, life or property. If it is determined that a dam is in an advanced state of deterioration and in such condition that continued deterioration could cause failure of the dam, the chief engineer may classify the dam as dangerous to public safety, life or property. If the chief engineer or council further determines that there is not sufficient time to issue an enforcement order to the owner to correct the hazard, or to take other legal action, the chief engineer or council may take any appropriate action necessary for emergency protection of public safety, life or property. The type of action depends upon the state of progression of the deterioration, the physical layout of the dam, reservoir and inundation zone below the dam, and the resources available to the chief engineer or council at the time of the emergency.

(2) The chief engineer or council, upon determining that a dam or reservoir is dangerous and constitutes a substantial threat of failure may request the attorney general or a prosecuting attorney to take any legal steps necessary for the protection of public safety, life or property. Such action may be brought in any county where the defendant or defendant's principal place of business is located or where the dam or reservoir is located. Nothing in this section shall preclude the chief engineer or council from taking immediate action under 10 CSR 22-4.010(1) above with respect to any dam or reservoir he has classified as dangerous to public safety, life or property.

Auth: sections 236.400, 236.405, 236.420, 236.425 and 236.455, RSMo. Original rule filed June 14, 1984, effective January 1, 1985.

10 CSR 22-4.020 Enforcement Orders and Enforcement Procedures

PURPOSE: The purpose of this rule is to identify the procedure to be taken for the issuance of enforcement orders.

(1) Enforcement orders shall be prepared by the chief engineer or council in cases where a dam or reservoir contains serious defects that pose a threat to public safety, life or property. Enforcement orders shall be sent to a dam owner by certified mail or served personally.

(2) If an owner does not initiate corrective actions to his dam and reservoir within thirty (30) days of the issuance of an enforcement order by the chief engineer or council, the council may request the attorney general or a prosecuting attorney to apply to the circuit court having jurisdiction to enforce compliance. Nothing in this section shall preclude the chief engineer from taking immediate action under 10 CSR 22-4.010(1) above with respect to any dam or reservoir he has classified as dangerous to public safety, life or property.

Auth: sections 236.400, 236.405, 236.410, 236.415, 236.445 and 236.450, RSMo. Original rule filed June 14, 1984, effective January 1, 1985.

REVISED STATUTES OF MISSOURI
CHAPTER 236
DAMS, MILLS, AND ELECTRIC POWER

Dam and Reservoir Safety

236.400. Definitions. As used in sections 236.400 to 236.500, standards, rules, and regulations promulgated hereunder, unless the context otherwise requires the following words and terms mean:

(1) **"Agricultural dam"**, any dam constructed to impound water for use in irrigation, livestock watering, or commercial fish rearing and sale;

(2) **"Alterations", "repairs",** or either of them, such alterations or repairs as affect the safety of a dam or reservoir, or public safety, life or property.

(3) **"Chief engineer"**, the head of the dam and reservoir safety program of the department of natural resources or his representative;

(4) **"Construction permit"**, a written authorization issued by the council giving the owner the right to construct, alter, enlarge, reduce, repair, or remove a dam or reservoir or appurtenances thereto, with such conditions as are necessary to adequately protect the public safety, life, property, the dam or reservoir;

(5) **"Dam"**, any artificial or manmade barrier which does or may impound water, and which impoundment has or may have a surface area of fifteen or more acres of water at the water storage elevation, or which is thirty-five feet or more in height from the natural bed of the stream or watercourse measured at the downstream toe of the barrier or dam, if it is not across a streambed or watercourse, together with appurtenant works. Sections 236.400 to 236.500 shall not apply to any dam which is not or will not be in excess of thirty-five feet in height or to any dam or reservoir licensed and operated under the Federal Power Act.

(6) **"Dam and reservoir safety council"**, as designed by sections 236.400 to 236.500 and referred to as the "council" shall consist of seven members appointed by the governor according to the provisions of sections 236.400 to 236.500;

(7) **"Director"**, the director of the department of natural resources of the state of Missouri;

(8) **"Enlargement"**, any change in or addition to an existing dam or reservoir which raises the height of a dam, increases the watershed for a reservoir, or raises the water storage elevation of the water impounded by a dam or reservoir;

(9) **"Experienced professional engineer"**, an engineer registered in the state of Missouri and experienced in hydraulics, hydrology and civil engineering as applied to dam design and construction;

(10) **"Maintenance"**, the proper keeping of all aspects of a dam or reservoir and appurtenances thereto, that pertain to safety, in a state of repair and working order as necessary to comply with sections 236.400 to 236.500, any permit hereunder, and protect public safety, life and property;

(11) **"Natural physical changes"**, those changes not directly or indirectly caused by man which affect the safety of the dam or reservoir.

(12) **"Operation"**, the physical changes, natural or manmade that occur or are made to a dam or reservoir, or operation of the mechanisms or appurtenances of the dam or reservoir which affect or may affect public safety, life or property;

(13) **"Owner"**, a person who owns, controls, operates, maintains, manages, or proposes to construct a dam or reservoir including:

(a) The state and its departments, institutions, agencies, and political subdivisions, but not the United States government;

(b) A municipal or quasi-municipal corporation;

(c) A district;

(d) A public utility;

(e) A natural person, firm, partnership, association, corporation, political subdivision, or legal entity;

(f) The duly authorized agents, lessees, or trustees of any of the foregoing;

(g) Receivers or trustees appointed by any court for any of the foregoing;

(14) **"Permit"**, a construction, safety, or registration permit;

(15) **"Permit applicant"**, an owner who applies for a construction, safety or registration permit.

(16) **"Reduction"**, any decrease in the height of a dam, watershed size, or watershed storage elevation of the water impounded by a dam or reservoir;

(17) **"Registration permit"**, a permit issued for a period not to exceed five years by the council to the owner of a dam and reservoir in existence on September 28, 1979, or which becomes subject to 236.500 for such dams and reservoirs which are in a properly maintained condition or which have made and complied with recommendations for corrections of observed defects of the dam or reservoir and have been* examined and approved in accordance with sections 236.400 to 236.500 and standards, rules and regulations and guidelines issued pursuant to sections 236.400 to 236.500.

(18) **"Reservoir"**, any impoundment which results from a dam as defined in sections 236.400 to 236.500;

(19) **"Safety permit"**, a permit issued to the owner for a period of five years, or less if safety considerations so require, by the council indicating that the dam meets the requirements of sections 236.400 to 236.500 and the guidelines, standards, rules and regulations issued pursuant to sections 236.400 to 236.500, and containing such conditions as to operations, maintenance and repair as are necessary to adequately protect public safety, life and the dam or reservoir.

(20) **"Water"**, water, other liquid or tailings.

(21) **"Water storage elevation"**, that elevation of water surface at the principal spillway which could be obtained by the dam or reservoir were there no outflow and were the reservoir full of water;

(22) **"Watershed"**, the area usually expressed in acres of square miles, that contributes or may contribute surface water to a reservoir.

(L. 1979 H.B. 603 § 1)

*Words "have been" not in original rolls.

236.405. Employment of engineer and assistants-records.- -1. There is hereby created a dam and reservoir safety program in the department of natural resources. The council shall promulgate rules, regulations, guidelines, and standards relating to the determination of whether a dam or reservoir constitutes a danger to public safety, life or property to be effective upon approval by the director.

2. The director of the department of natural resources shall employ an experienced professional engineer as chief engineer and assistants to administer the activities of the dam and reservoir safety program.

3. The chief engineer shall be selected under the state merit system on the basis of professional experience directly related to the design and construction of dams and reservoirs.

4. The findings, opinions, and orders of the council and the chief engineer shall be kept as permanent public records in the offices of the department of natural resources.

(L 1979 H.B. 603 § 2)

236.410. Council established-members, terms, qualifications, officers-meetings-quorum-compensation.- -1. There is hereby created a "Dam and Reservoir Safety Council" whose domicile for the purposes of sections 236.400 to 236.500 shall be the department of natural resources of the state of Missouri, for the regulation of dam and reservoir safety. The council shall consist of seven members, no more than four of whom shall be members of the same political party, appointed by the governor with the advice and consent of the senate.

2. The members of the council shall have a background of academic training or professional experience directly related to the design of dams and reservoirs. At least two members of the council shall

be professional engineers registered in the state of Missouri, one of whom shall represent the general public; at least one member shall be an engineering geologist; at least one member, in addition to the professional engineer, shall be a representative of the general public, and two members shall be from industry, one of whom shall be an earthmoving contractor; and one member shall be the owner of a dam or reservoir. The members shall serve for a term of two years; except, of the first appointments three shall be appointed for one year. The governor shall fill any vacancy on the council and may remove any appointed member for cause. The council shall annually elect a chairman and vice-chairman from among its members. The council shall meet regularly but not less than quarterly. Special meetings and hearings may be called upon delivery of written notice to each member of the council signed by the director, the chief engineer, the council chairman, or four of the council members. Four members of the council shall constitute a quorum to transact the business of the council. The council shall decide all questions by a majority vote of those present and constituting a quorum. The members of this council shall not receive any compensation other than for actual travel and subsistence when acting officially as members of the council.
(L. 1979 H.B. 603 § 3)

236.415. Council's powers and duties-public hearings required-adoption of rules and regulations, procedure-suspension and reinstatement, procedure.- -1. The council considering recommendations of the chief engineer shall, subsequent to a public meeting, adopt, subject to the approval of the director, the general technological guidelines and the standards, guidelines, rules and regulations applicable to permits, the design, construction, maintenance, operation, alteration, repair, enlargement, reduction, removal or natural physical changes that may occur to a dam or reservoir. Violations of guidelines, standards, rules and regulations are violations of sections 236.400 to 236.500 permitting the revocation, suspensions, or refusal to issue any permit required by sections 236.400 to 236.500. No standards, guidelines, rules or regulations shall be adopted, or any amendment or repeal thereof shall be effective, except after a public hearing to be held after thirty days prior notice by advertisement or press release, and publication as required in chapter 536, RSMo, of the date, time and place of the hearing and opportunity given to the public to be heard.

2. At the hearing, opportunity to be heard by the council with respect to the subject thereof shall be afforded any interested person upon written request to the council, addressed to the chief engineer, received not later than seven days prior to the hearing and may be afforded to other persons if convenient. In addition, any interested person, whether or not heard, may submit, within seven days subsequent to the hearings, a written statement of his views. The council may solicit the views, in writing, of persons who may be affected by, or interested in, proposed rules and regulations, standards or guidelines. Any person heard or represented at any hearing or making written request for notice shall be given written notice of the action of the council with respect to the subject thereof.

3. The council upon hearing the recommendations of the chief engineer and reviewing the application for a construction or registration permit shall approve or deny the permit application. The council may delegate authority to approve or deny permit applications to the chief engineer, whose actions shall be subject to appeal to the council as provided in subsection 2 of section 236.425.

4. No standard, rule or regulation or guideline, or amendment or repeal thereof, adopted by the council shall be in force and effect until it has been approved in writing by the director and the requirements of chapter 536, RSMo, are satisfied. The affirmative vote of at least four members of the council shall be required for adoption. Any rule or portion of a rule promulgated pursuant to sections 236.400 to 236.500 may be suspended by the joint committee on administrative rules if after hearing thereon the committee finds that such rule or portion of the rule is beyond or contrary to the statutory authority of the agency which promulgated the rule, or is inconsistent with the legislative intent of the authorizing statute. The general assembly may reinstate such rule by concurrent resolution signed by the governor.
(L 1979 H.B. 603 § 4)

236.420. Inspection of dams and reservoirs, when-report on conditions.- -The council, with the advice and assistance of the chief engineer, shall carry out a state program of inspection of dams and reservoirs in accordance with regulations adopted by the council. All dams and reservoirs in this state shall be inspected on a periodic basis to determine if they constitute a threat to public safety, life or property. The chief engineer shall submit reports to the

director and the council concerning the condition of each dam or reservoir inspected, and the recommendations as to any alterations or repairs needed.

(L 1979 H.B. 603 § 5)

236.425. Chief engineer's duties-search warrants-council to hear certain appeals.- -1. The chief engineer shall administer the provisions of sections 236.400 to 236.500 by:

(1) Recommending general technological guidelines that pertain to the design, construction, maintenance, operation, use alteration, repair, enlargement, reduction, or natural physical changes of, or that may occur to, a dam or reservoir including their removal; except that, detailed technical specifications shall not be promulgated to regulate the design, construction, operation, maintenance, use, alteration, repair or removal of a dam or reservoir. Such guideline shall not be effective until adopted by the council and approved by the director at a public meeting, after notice requirements set forth in subsection 1 of section 236.415 herein have been satisfied;

(2) Making* recommendations concerning the issuing, continuing in effect, revoking, modifying suspending, or denying, under such conditions as prescribed by sections 236.400 to 236.500 and such rules as may be adopted to protect public safety, life, property, dams and reservoirs, construction permits for the construction, alteration, enlargement reduction, repair or removal of dams or appurtenances thereto, and safety and registration permits to insure continuing protection of public safety, life, property, dams and reservoirs, for all dams subject to the provisions of sections 236.400 to 236.500.

(3) Making such investigations, including hearings, as are proper to protect public safety, life and property from an unsafe dam or reservoir, and to determine whether any permits should be issued, continued, revoked, modified, suspended, or denied or whether any violations of sections 236.400 to 236.500, standards, or rules or regulations have occurred or are occurring;

(4) Entering, at any reasonable time, any private or public premises as necessary to make an investigation or inspection of a dam or reservoir, or records kept, pertaining thereto, and such inspection shall follow reasonable notice to the owner given prior to such investigation or inspection except in the case of an emergency threatening public safety, life or property, in which case such inspection or investigation may be made without prior notice. A suitably restricted search warrant, upon a showing of probable cause in writing and upon oath, shall be issued by any judge or magistrate having jurisdiction, to the chief engineer or his representative for the purpose of enabling him to make the inspection.

2. The council shall meet with or hear the appeal of a permit application and his representative upon request of the permit applicant if the chief engineer has rejected the application for a construction, safety, or registration permit.

(L 1979 H.B. 603 § 6)

*Words "To Make" appear in original rolls.

236.430. Employees, council to provide for.- -The council shall retain, employ, provide for and compensate within appropriations available therefore, such consultants, assistants, and other employees on a full-or part-time basis as may be necessary to carry out the provisions of sections 236.400 to 236.500 and prescribe the times at which they shall be appointed and their powers and duties.

(L 1979 H.B. 603 § 7)

236.435. Permits required, when, procedure to obtain-chief engineer to make recommendation-exemptions-plans to be filed.- -1. Prior to the commencement of the construction, alteration, enlargement, reduction or removal of a dam or reservoir, the owner shall apply to the council and upon satisfying the requirements of sections 236.400 to 236.500 and the rules, regulations and standards promulgated pursuant hereto, obtain a construction permit.

2. The application for a construction permit shall bear the seal and signature of an experienced professional engineer registered in Missouri or employed by a qualified engineering division of a state or federal agency regularly engaged in dam construction for soil and water conservation, or irrigation or relating to wildlife conservation and shall be accompanied by the design report and plans and specifications of the proposed design, alteration, enlargement, reduction, repair or removal of the dam or reservoir.

3. Any person constructing or owning a dam or reservoir, or living or owning property in an area affected, or whose safety may be affected by such dam or reservoir may consult with the chief engineer concerning such dam or reservoir.

4. The council upon hearing the recommendations

of the chief engineer shall approve or deny an application for a construction permit within forty-five days after its receipt or the completion of any hearings in connection with such application, whichever is later. The permit shall be issued upon the receipt of the application if, in the judgement of the council, requirements of sections 236.400 to 236.500 and all standards, rules and regulations hereunder are satisfied and the design will be adequate to protect the public safety, life and property.

5. The council upon hearing the recommendation of the chief engineer may reject the application if it decides that there is insufficient information to determine the safety of the proposed construction, alteration, enlargement, reduction or removal of the dam or reservoir would endanger public safety, life or property, or otherwise not comply with sections 236.400 to 236.500 and any rules, standards, guidelines and regulations adopted hereunder.

6. A landowner that now owns or proposes to construct an agricultural dam or reservoir, which will be used primarily for agricultural purposes, will be exempt from all provisions of sections 236.400 to 236.500. If the council, with the advice of the chief engineer, determines that the dam or reservoir is no longer used primarily for agricultural services, it shall become subject to the provisions of sections 236.400 to 236.500.

7. Dams or their construction, alterations, enlargements, reductions or removals designed by, and their construction, alteration, enlargement, reduction or repair or removal monitored by, a qualified engineer regularly engaged in dam construction for soil and water conservation or irrigation or relating to wildlife conservation are for the purposes of such construction or other listed actions exempt from the provisions of this section except that the plans for the dam shall be filed with the chief engineer prior to construction, or other listed action. Amended plans shall be filed at the completion of construction or other listed action if there have been significant deviations from the previously filed plans.

(L 1979 H.B. 603 § 9)

236.440. Owner to notify council, when-council to issue safety permit-registration of existing dams, when-violations.- -1. The owner shall notify the council upon completion of construction, alteration, enlargement, or reduction of the dam and reservoir. This notification shall bear the seal and signature of an experienced professional engineer and shall be accompanied by an application for a safety permit. The owner of any dam or reservoir subject to the provisions of sections 236.400 to 236.500 shall obtain a safety permit following completion of construction.

2. Upon receipt of complete and proper application for a safety permit, including notification of completion by the owner and certification by an experienced professional engineer that the new construction, alteration, enlargement or reduction has been completed in accordance with the provisions of the construction permit and sections 236.400 to 236.500, the council shall upon receipt of the application issue a safety permit. The council upon advice of the chief engineer may deny the application if it determines that violations of the construction permit or sections 236.400 to 236.500 exist. If revisions have been made which vary substantially from the provisions of the construction permit, it must be shown that the revisions do not endanger public safety, life or property. The safety permit for dams constructed pursuant to a construction permit issued under sections 236.400 to 236.500, may contain conditions the council upon advice of the chief engineer determines are necessary for the protection of public safety, life or property and a schedule and timetable for the dam and reservoir to achieve compliance with the construction permit and provisions of sections 236.400 to 236.500, standards, rules and regulations promulgated hereunder, but such conditions shall not be more stringent or restrictive than those contained in the construction permit.

3. Owners of dams and reservoirs in existence on September 28, 1979, shall obtain registration permits for dams of fifty to seventy feet in height within four years, and for dams up to fifty feet in height within six years of September 28, 1979, or as otherwise required by the provisions of sections 236.400 to 236.500 and rules and regulations adopted hereunder. A registration permit shall be issued by the council upon the advice of the chief engineer for dams and reservoirs only after it is determined that the dam meets the standards of sections 236.400 to 236.500 and rules and regulations hereunder, and any recommendations made by the inspecting engineer pursuant thereto.

4. Upon complete and prior application for a registration permit, on forms provided by the department of natural resources, by the owner of a dam in existence upon September 28, 1979, including a cer-

tification by an experienced professional engineer or an engineering division of state or federal agency regularly engaged in dam construction for soil or water conservation, irrigation, or relating to wildlife conservation, that the dam has been inspected in accordance with sections 236.400 to 236.500, standards, rules and regulations and guidelines promulgated hereunder, and that the owner has complied with the inspecting engineer's or agency's recommendations necessary to correct observed defects of the dam or reservoir, the council shall, upon receipt of the application, issue a registration permit. The council upon hearing the recommendations of the chief engineer may deny the application if it determines that the owner has not complied with the inspecting engineer's or agency's recommendations.

5. For dams for which construction was completed prior to the effective date of the construction permit requirements hereunder, the registration permit may contain conditions the council upon hearing recommendations of the chief engineer determines to be necessary to bring the dam and reservoir into compliance with sections 236.400 to 236.500 and standards, rules and regulations promulgated hereunder.

6. If a dam or reservoir has been removed by the owner, the council shall issue a final approval upon notification by the owner and receipt of certification by an experienced professional engineer that the removal has been carried out in accordance with the provisions of the construction permit issued for such removal. Failure to obtain final approval shall be a violation of sections 236.400 to 236.500.

7. The council shall issue safety permits for dams or their construction, alterations, enlargements reductions or removals designed by, and their construction or other listed actions monitored by, a state or federal agency engaged in dam construction for soil and water conservation, irrigation or relating to wildlife conservation provided the owners obtain from such agency and file with the chief engineer a statement upon completion of the construction or other listed actions and at not greater than five year intervals, and with every application for renewal of a safety permit, that the dam conforms to the plans on file with the chief engineer and is in a safe, properly maintained condition.

8. The owner shall apply for renewal of a safety or registration permit not less than sixty days prior to expiration of the previously issued permit. The chief engineer shall determine if the dam and reservoir are essentially as described in the latest permit issued for that dam and reservoir, whether they satisfy the requirements of sections 236.400 to 236.500 and any rules, regulations, standards and guidelines adopted pursuant to sections 236.400 to 236.500 and whether any inspections conducted in connection with the permit renewal reveals any defect in the dam or reservoir which would threaten public safety, life or property. Unless the chief engineer determines that the dam and reservoir are not properly maintained, do not satisfy the requirements of the permit, act* of rules, regulations, standards and guidelines promulgated hereunder, or that defects revealed by the inspection are not corrected, the council upon hearing the recommendations of the chief engineer shall issue or renew the safety or registration permit upon forty-five days of the receipt of a complete and proper application. The council may require the owner to furnish a certification, as a part of an application to renew a permit hereunder, by an experienced professional engineer or a qualified engineering division of a state or federal agency regularly engaged in dam construction for water conservation, irrigation or relating to wildlife conservation that the dam is in a properly maintained condition and that any recommendation for correction of defects which violate sections 236.400 to 236.500, guidelines, rules, regulations and standards hereunder or which threaten public safety, life or property have been complied with and that the engineer detected no other such defects which have not been corrected.

9. If a barrier or water impoundment becomes a dam or reservoir through alteration or enlargement as defined herein, it shall be subject to the provisions of sections 236.400 to 236.500.

10. Failure to obtain and comply with a permit as required in this section is a violation of sections 236.400 to 236.500.

(L.1979 H.B. 603 § 9)

* Word "act" apparently refers to "this act," now 236.400 to 236.500.

236.445. Permit may be suspended-alteration or removal may be required-violation.- -1. If it is found that a dam or reservoir presents a threat to public safety, life or property, or that the safety of the dam or reservoir is threatened, the permit for

the dam or reservoir shall be suspended and shall be reinstated only when the owner at his expense has completed the necessary alteration or has established such operational procedures as the council upon hearing the recommendations of the chief engineer deems necessary for the protection of the public safety, life, property, the dam or reservoir. If necessary for such protection, the council may require the owner at his expense to remove the dam or reservoir, or if the owner refuses or neglects to act, the state may alter or remove the dam or reservoir, and the chief engineer may recover the costs of such action as provided in section 236.450.

2. If the owner refuses to alter or remove a dam or reservoir as directed when found to be a threat as set forth in sections 236.400 to 236.500, he shall be in violation of sections 236.400 to 236.500 and the permit requirements hereunder and such action shall subject the owner to the enforcement provisions contained herein and revocation of the permit.

(L. 1979 H.B. 603 § 10)

236.450. Removal or repair of abandoned dam-recovery of expenses.- -An existing dam or reservoir which the chief engineer determines to be abandoned and considered to be a threat to public safety, life, or property may be altered, repaired, or removed upon such determination at the expense of the state of Missouri, and the chief engineer may request either the attorney general or a prosecuting attorney to bring an action in the name of the people of the sate of Missouri to recover such expenses from the owner through appropriate legal processes. Such action may be brought in any county where the defendant or defendant's principal place of business is located or where the dam or reservoir is located.

(L. 1979 H.B. 603 § 11)

236.455. Emergency action authorized.- -If it is determined at any time that the condition of a dam or reservoir is an imminent and substantial threat, and so dangerous to public safety, life or property as not to permit time for issuance of an enforcement order to correct the hazard, the chief engineer may take any appropriate action not prohibited by the constitution or laws of the state he deems necessary for emergency protection of public safety, life or property and may request the attorney general or a prosecuting attorney to take any legal steps necessary to accomplish such action and to recover the cost of such measures from the owner by appropriate legal action.

(L. 1979 H.B. 603 § 12)

236.460. Transfer of ownership, notice required.- -The owner shall notify the chief engineer upon the sale or other transfer or interest in a dam or reservoir, either existing or under construction, alteration or removal. The construction, safety or registration permit shall be transferred to the successive owner upon receipt of this notification and upon determination that such transfer will not endanger public safety, life, property, the dam or reservoir.

(L. 1979 H.B. 603 § 13)

236.465. Industrial water retention structures subject to provisions of sections 236.400 to 236.500-inspection-changes.- -Irrespective of any other provisions of sections 236.400 to 236.500, the following provisions shall apply to the construction, alteration or enlargement of tailing, slime and settling ponds and to other similar industrial water retention structures included within the definitions of dam or reservoir in section 236.400:

(1) Applications for construction, safety or registration permits shall be submitted as provided in section 236.435 and section 236.440 except that design plans and specifications which outline any anticipated enlargement of the industrial water retention structure shall be included;

(2) It shall not be necessary to reapply for a permit each time the structure is enlarged if the enlargement plans have been submitted in and approved with the original application, and the provision of subdivision (3) of this section have been satisfied.

(3) Upon notification of the chief engineer, bearing the seal and signature of an experienced professional engineer, that the initial phase of construction has been completed in accordance with the provisions of the construction permit and sections 236.400 to 236.500, or if a registration permit has been issued as provided in subdivision (1) of this section, and before any enlargement is begun, and if no violation of sections 236.400 to 236.500 can be shown, a safety permit or a registration permit with special provisions that authorize the planned enlargement to the initially constructed structure shall be issued, on application, if enlargement plans were included and approved in the original application;

(4) It is not necessary to retain continuously a professional engineer after the initial stage of construction;

(5) The dam shall be inspected by an experienced professional engineer registered in the state of Missouri as required to renew the safety permit or registration permit at five-year intervals unless safety or the public, life and property require a shorter period of time;

(6) The chief engineer shall make inspections of these structures as necessary to insure adequate protection for public safety, life and property;

(7) Where it is shown that a tailings, slime and settling pond, or other similar water retention structure is subject to inspection for safety, using standards at least as stringent as those required under sections 236.400 to 236.500, by a federal or state agency and the owner notifies the council that the structure is subject to such inspection, such structures shall be exempt from the provisions of sections 236.400 to 236.500.

(L. 1979 H.B. 603 § 14)

236.470. Conduct of hearings subpoenas-approval of final orders.- -1. At any public hearing all testimony taken before the council, or a hearing officer appointed by the council chairman, shall be under oath and recorded stenographically. The transcript so recorded shall be made available to any person upon payment of the usual charge therefore;

2. In any such hearing, any member of the council or the hearing officer shall issue in the name of the council notice of hearing and subpoenas. Subpoenas shall be issued and enforced as provided in section 536.077, RSMo. The rules of discovery that apply in any civil case apply to hearings held by the council.

3. All hearings to approve, amend or repeal guidelines, standards or rules and regulations shall be held before at least four members of the council.

4. All other hearings may be held before one council member designated by the council chairman or a hearing officer who shall be a member of the Missouri bar and appointed by the council chairman. The hearing officer or council member shall preside at the hearing and hear all evidence and rule on the admissibility of evidence. The hearing officer or council member shall make recommended findings of fact and may make recommended conclusions of law to the council.

5. All final orders or determinations or other final actions by the council shall be approved in writing by at least four members of the council. Any council member approving in writing any final order or* determination or other final action, who did not attend the hearing, shall do so only after reviewing all exhibits and reading the entire transcript.

(L. 1979 H.B. 603 § 15)

*Word "of" appears in original rolls.

236.475. Immunity of officers.- -In the absence of willful and wanton misconduct, no action shall be brought against the council, the chief engineer or his agents, or department employees or private individuals employed as consultants by the department for the recovery of damages caused by the partial or total failure of any dam or reservoir or through the use or operation of any dam or reservoir upon the ground that such person is liable for virtue of any of the following:

(1) The approval of a dam or reservoir or permits therefore;

(2) The issuance or enforcement of orders relating to maintenance, operation, or repair of a dam or reservoir;

(3) Control and regulation of a dam or reservoir;

(4) Measures taken to protect against failure during an emergency.

(L. 1979 H.B. 603 § 16)

236.480. Judicial review of actions-administrative review required-interpretation of administrative actions.- -1. All final decisions, orders, actions or determinations made pursuant to the provisions of sections 236.400 to 236.500 are subject to judicial review pursuant to the provisions of chapter 536, RSMo. No judicial review shall be available, however, until all administrative remedies are exhausted.

2. In any suit filed pursuant to section 236.400 to 236.500, RSMo, concerning the validity of the standards, rules, guidelines and regulations promulgated hereunder, the court shall review the record made pursuant to their adoption to determine the validity and reasonableness of such standards, rules, guidelines and regulations and may hear such additional evidence as it deems necessary.

(L. 1979 H.B. 603 § 17)

236.485. Water rights preserved.- -The provisions of sections 236.400 to 236.500 do not grant or diminish any right to that water entering, discharged from or impounded by a dam or contained in a reservoir.

(L. 1979 H.B. 603 § 18)

236.490. Enforcement of act.- -All duly constituted officers of the law of this state or any political subdivision thereof shall aid in the enforcement of the provision of sections 236.400 to 236.500.

(L. 1979 H.B. 603 § 19)

236.495. Legal actions for enforcement available, procedure.- -1. In carrying out the provisions of sections 236.400 to 236.500 and to the extent not inconsistent with chapter 491, RSMo, the chief engineer or council may subpoena witnesses and compel their attendance, and may also require the submission of books, papers, documents or other pertinent data in any hearing or enforcement proceedings hereunder or in any case wherein a violation of this chapter is alleged. Upon failure or refusal to comply with such order or upon failure to honor a subpoena, as herein provided, the council may request the attorney general or a prosecuting attorney to apply to the circuit court having jurisdiction to enforce compliance.

2. The council may request the attorney general or a prosecuting attorney, in the name of the state, to institute a suit for injunctive relief to stop or prevent violations of the provisions of sections 236.400 to 236.500,permits, standards, orders and rules and regulations promulgated hereunder, which shall be violations of sections 236.400 to 236.500, or to restrain any violation thereof, or after written notification of violation by the council, and a reasonable time to correct such violation, for the assessment of a penalty of up to one thousand dollars per day, for each day or part thereof the violation continues to occur after such notice. Such action may be brought in any county where the defendant's principal place of business is located, where the dam or reservoir is located, or the violation does or may occur.

(L. 1979 H.B. 603 § 20)

236.500. Penalties.- -1. Any person who willfully violates any of the provisions of section 236.400 to 236.500 is guilty of a misdemeanor and, upon conviction, shall be punished by a fine of not less than five hundred dollars nor more than ten thousand dollars, or by confinement in the county jail for a term of not less than thirty days nor more than one year, or by both such fine and confinement.

2. In the event of a continuing violation, each day that the violation continues shall constitute a separate and distinct offense.

3. Any person who willfully obstructs, hinders or prevents the council, the chief engineer or his agents or employees from performing the duties imposed by sections 236.400 to 236.500 and rules and regulations promulgated hereunder or who willfully resists the council, the chief engineer, or his agents in the performance of the duties imposed on them by sections 236.400 to 236.500 and rules and regulations promulgated hereunder is guilty of a misdemeanor and, upon conviction, shall be punished as provided in subsection 1 of this section.

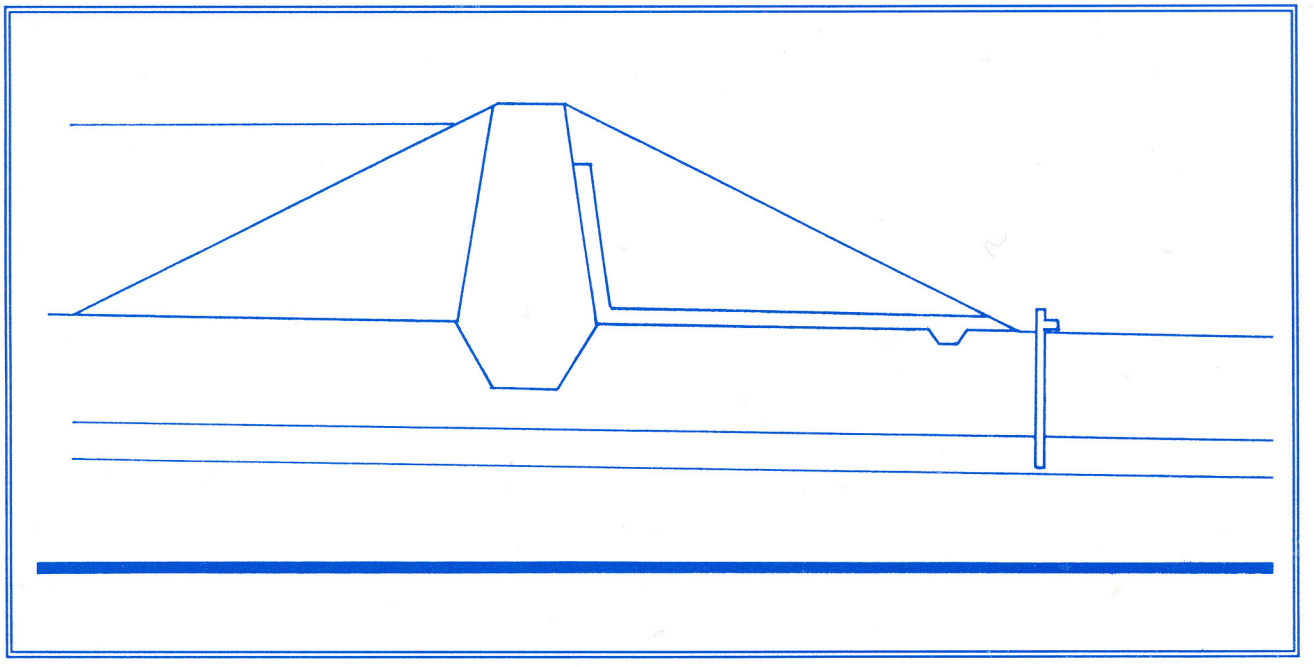
4. Any owner who willfully engages in the construction, repair, alteration or removal of any dam or reservoir without a construction permit or in violation of a construction permit or willfully violates the requirements of or for a safety or registration permit is guilty of a misdemeanor and, upon conviction, shall be punished as provided in subsection 1 of this section.

(L. 1979 H.B. 603 § 21)

ENGINEERING ANALYSIS

OF

DAMS



BY
BRIAN J. SWENTY

MISSOURI DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND LAND SURVEY
DAM AND RESERVOIR SAFETY PROGRAM

AUGUST 1989

FOREWORD

The first state legislation aimed at regulating dams was passed in 1889 and was called the Dams, Mills, and Electric Power Law. That law was concerned only with damages caused by construction and lake formation. It did not address the engineering aspects of design or safety of dams.

During the period 1977-81, the Corps of Engineers conducted a nationwide inventory and inspection of dams. The results indicated that Missouri ranked fourth in the United States in total number of dams and first in the total number of unsafe dams. Of 613 dams inspected, approximately 75% were considered unsafe. The final report submitted to Congress by the Corps cited Missouri as having inadequate legislation, regulatory procedures, technical staff, and funding.

In September 1979, the Governor signed House Bill 603 into law. The bill became sections 236.400 through 236.500 RSMo and is known as the dam safety law. It authorized the creation of a Dam and Reservoir Safety Council appointed by the Governor and a staff within the Department of Natural Resources to implement the law. Regulations were approved in August 1981 and Missouri began the process of upgrading unsafe dams.

Only dams 35 feet or greater in height are regulated by the Natural Resources' Division of Geology and Land Survey, dam and reservoir safety program. Exemptions to the dam safety law include:

- dams owned and operated by the federal government
- dams licensed by the Federal Energy Regulatory Commission
- dams impounding water used primarily for agricultural purposes

During the past eight years, numerous owners have had their dams inspected in accordance with the law. As these dams were evaluated and analyzed, it became clear that an engineering analysis manual was needed to provide engineers with a technical reference to perform their computations. An abundance of engineering text books, design manuals, and construction guidelines have been written which pertain to the design of dams, but there are few booklets dedicated to the subject of dam safety analysis.

Dam Safety is a complex issue. To determine whether a dam is safe requires a knowledge of hydrology, hydraulic engineering, geotechnical engineering, geology, seismology, surveying, and structural analysis. This manual is intended to provide engineers with a description of analytical techniques that can be used to evaluate the safety of dams.

Two of the goals of the dam safety law are to ensure that new dam construction meets minimum safety standards and defects at older unsafe dams are eliminated. It is my hope that this manual will provide the technical assistance necessary to accomplish these goals.

G. Tracy Mehan III
Director, Missouri Department of Natural Resources

ENGINEERING ANALYSIS OF DAMS

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CHAPTER I

INTRODUCTION

The purpose of this booklet is to provide engineers with information regarding the analysis of dams in Missouri. This booklet does not represent and should not be considered a comprehensive step-by-step set of requirements for dam design and analysis. It should be used simply as a technical reference. No discussions were included regarding the preparation of plans and specifications for new dams. Other agencies, such as the Soil Conservation Service, the U. S. Army Corps of Engineers, and the Bureau of Reclamation, have publications which deal with this topic.

There are many acceptable methods that can be used to perform an engineering analysis of a dam and spillway. Suggested standards are listed in this booklet along with recommended methods and references. When a permit application is submitted to the Dam and Reservoir Safety Program, the engineering computations are reviewed by the Chief Engineer and his staff on a case-by-case basis. Engineers may use methods of analysis and design which differ from those presented in this manual. Latitude is provided to engineers who use other methods which produce a product that meets the minimum safety criteria in the regulations and the dam safety law.

A typical analysis includes all or part of the following aspects of engineering:

- Hydrological
- Hydraulic
- Geotechnical
- Structural Stability
- Seismic
- Geological

In this manual the word "dam" refers to any artificial or manmade barrier which is 35 feet or more in height measured either from the natural bed of the stream or watercourse or lowest point on the toe of the dam (whichever is lower) up to the crest elevation, together with appertenant works. Dams less than 35 feet in height are not regulated by the Dam and Reservoir Safety Program.

The objective of the Missouri Department of Natural Resources, Dam and Reservoir Safety Program is to insure that dams in Missouri are safely constructed, operated, and maintained. The Code of State Regulations contain minimum safety criteria for both new and existing dams. New dams are those constructed after August 13, 1981.

There are several differences between the criteria for new and existing dams. For example, engineers do not have to show that existing dams meet the stability criteria unless significant modifications are made to the height, slope, or water storage elevation. The seismic criteria apply only to new dams. For a complete description of the applicable criteria, see 10 CSR 22-3.020.

Geological considerations are very important in the analysis and design of new dams. A short discussion of geology and its relationship to dams is included in this booklet. More detailed information, such as geological maps, bore logs, and publications on Missouri geology, can be obtained from the Department of Natural Resources, Division of Geology and Land Survey.

New construction and the analysis of existing dams require field surveys of the embankment and spillways. A chapter on engineering surveying has been provided in this manual. Under Missouri law, engineering surveys can be performed by a registered professional engineer; however, boundary and property surveys must be performed by a registered land surveyor.

The appendices contain copies of permit applications and certification forms for engineers. For more information, contact:

Chief Engineer
Dam and Reservoir Safety Program
Department of Natural Resources
P.O. Box 250
Rolla, Missouri 65401
Phone (314) 364-1752

CHAPTER II

PERMITS

The owner of a proposed new dam 35 feet or more in height is required to obtain a construction permit to build the dam and a safety permit to operate the dam and reservoir. Owners of existing dams 35 feet or more in height are required to obtain registration permits in accordance with the schedule in 10 CSR 22-2.020(2). Significant modifications to existing dams also require a construction permit. Significant modifications are defined in 10 CSR 22-1.020(50). Exemptions from these permit requirements have been provided in the dam safety law for the federal government and owners of agricultural dams which were constructed in accordance with 10 CSR 22-2.010(3).

A. Construction Permits

In order to show that a dam will meet the minimum safety criteria in the code of state regulations, an engineering report must be submitted with the permit application, plans, and specifications. In most cases, hydrologic, hydraulic, geotechnical, and structural computations must be performed. Sufficient detail must be included in the report for the analysis to be verified. The staff of the Dam and Reservoir Safety Program does not perform a comprehensive check of the engineer's computations. Instead, data is taken from the engineers report and an independent analysis is performed to insure that the minimum safety standards are met. If a discrepancy is found between the results of the staff analysis and the engineer's report, the engineer's computations are examined in more detail to resolve the problem.

When a construction permit is issued to build or modify a dam, the owner is required to notify the Chief Engineer when construction begins. An engineer from the Dam and Reservoir Safety Program normally inspects new dam sites during three key activities; the construction of the core trench, construction of internal drains, and installation of pipes through the embankment. It is important for the owner to maintain communication with his engineer, the contractor, and the Dam and Reservoir Safety Program staff throughout construction. Inspections during critical construction activities provide information needed to prepare as-built drawings and safety permit applications following construction.

Construction permits are normally issued for a period of one year to start construction and one additional year to complete construction.

B. Safety Permits

A safety permit is basically an operating permit for dams that were constructed after August 13, 1981. A copy of the permit application and the checklist used to review the applications are included in Appendix A. The owner's engineer must submit a certification that the dam was built substantially in accordance with the approved plans and specifications. Safety permit applications must include as-built drawings if significant modifications were made to the original design drawings during construction. Appropriate engineering computations should accompany the application if as-built drawings are submitted.

Safety permits are usually issued for a period of 5 years. During this time, the owner must maintain the dam in accordance with an approved maintenance and operation plan. The Missouri Department of Natural Resources (1986) published the booklet, Maintenance, Inspection, and Operation of Dams in Missouri which is a good reference for developing a maintenance and operation plan.

Sixty days prior to the expiration of the safety permit, the owner should contact the staff of the Dam and Reservoir Safety Program and request a permit renewal inspection. The permit renewal inspection includes visual observations of the dam, a review of maintenance records, and a site visit to the area downstream of the dam. Assuming no observable defects are found and the downstream hazard zone is unchanged, the permit is renewed for an additional five year period. If changes in the downstream hazard zone require spillway or dam crest modifications, a construction permit must be obtained to perform the work.

Safety permits for tailings dams constructed after August 13,1981 include provisions for phased, stepped, or continuous construction. They must be renewed at five year intervals or whenever major changes are made to the plans and specifications on file with the Dam and Reservoir Safety Program. Safety permits are required for tailings dams after closure of the mining and milling operation unless the dams meet the retaining/retarding structure exemption criteria listed in 10 CSR 22-2.010(7).

C. Registration Permits

There are approximately 640 dams in Missouri that are regulated by the Dam and Reservoir Safety Council. Over 95% of these dams were constructed prior to August 13, 1981. These older dams must be operated under the provisions of a registration permit. Like safety permits, registration permits are operating permits for dams that have been shown to meet the minimum safety criteria in the dam safety law.

Before a registration permit can be issued, the dam must be inspected and analyzed to show that it meets the

minimum safety standards in the Rules and Regulations of the Dam and Reservoir Safety Council. Dams must have sufficient spillway capacity to pass the design flood without overtopping and all observable defects must be corrected or monitored. Observable defects are described in 10 CSR 22-3.030(1)(A)1. Stability calculations are not required unless significant modifications are made to the height of the dam, the slopes, or the water storage elevation. Hydrologic and hydraulic calculations should be included in the inspection report or in a separate engineering report. If the dam must be modified to correct observable defects, a construction permit may be required depending on the extent of the modifications.

In addition to the spillway calculations, two certifications, a statement concerning the stability of the dam, and a maintenance and operation plan must be submitted prior to issuance of the first registration permit. A blank registration permit application, a review checklist, and a standard certification form are included in Appendix A. The booklet, Maintenance, Inspection, and Operation of Dams in Missouri is a good reference for developing a maintenance and operation plan.

Sixty days prior to the expiration of the registration permit, the owner should contact the staff of the Dam and Reservoir Safety Program and request a permit renewal inspection. Assuming no observable defects are found and the downstream hazard zone is unchanged, the permit is renewed for an additional five year period. If changes in the downstream hazard zone require spillway or dam crest modifications, a construction permit must be obtained to perform the work.

Registration permits for tailings dams in existance before August 13,1981 can include provisions for phased, stepped, or continuous construction. They must be renewed at five year intervals or whenever major changes are made to the plans and specifications on file with the Dam and Reservoir Safety Program. Registration permits are required for tailings dams after closure of the mining and milling operation unless the dams meet the retaining/retarding structure exemption criteria in 10 CSR 22-2.010(7).

CHAPTER III

HYDROLOGIC CONSIDERATIONS

The analysis of an existing dam and the design of a new dam includes the hydrological analysis of the watershed and a hydraulic analysis of the spillways. Generally the hydrologic computations conclude with the computation of the inflow hydrograph to the reservoir. Parameters used in the hydrologic analysis include the watershed area, unit hydrograph parameters, lag time, total rainfall, rainfall distribution (hyetograph), infiltration characteristics of the watershed, and initial abstraction. In the case of kinematic and dynamic wave modeling and breach analysis, channel routing will also be included in the definition of hydrological computations.

Hydraulic computations involve reservoir routing and rating open channel and closed conduit spillways. This differentiation, although not universal in the field of civil engineering, will nonetheless be used throughout this booklet.

The flood used for design to prevent the failure of the dam is termed the "spillway design flood" (SDF). As defined in 10 CSR 22-1.020 (52), the spillway design flood is the specified flood discharge that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in an area and for which the dam and reservoir are designed. Determination of the spillway design flood is based on a rational consideration of the chances of the simultaneous occurrence of several elements or conditions which contribute to the flood. A major aspect of the spillway design flood computation is the determination of the runoff that would result from an occurrence of a percentage of the probable maximum precipitation. This hydrometeorological approach is necessary because contemporaneous site-specific meteorologic and streamflow data do not exist for most small watersheds in Missouri. If actual streamflow records of considerable length are available for the general region in which the dam is located, this data should be used in the determination of the SDF. This chapter, however, is primarily concerned with synthetic hydrology and techniques used to simulate the rainfall runoff process on a watershed.

A. Downstream Environment Zone

The downstream environment zone is defined as an area downstream from a dam that would be affected by inundation in the event the dam failed with the reservoir at the emergency spillway crest elevation or the dam crest elevation, in the absence of an emergency spillway. This is typically termed a "sunny-day" failure. Inundation is defined as a minimum of 2 feet of water over the first floor elevation of affected structures. Three environmental classes are defined in 10 CSR 22-2.040(1). Class I is high hazard, Class II is significant hazard, and Class III is low hazard. If a sufficient number of homes are located downstream of a dam, a breach analysis is required to justify a Class II or Class III downstream environmental zone designation. It may be advantageous to the engineer performing the computations to meet with the staff of the Dam and Reservoir Safety Program before a breach analysis is conducted. In many cases, a downstream enviornmental zone classification can be agreed upon without computations.

A dam breach analysis involves a specific analytical approach rather than the use of procedures described for spillway design. There are many models available for performing a breach analysis. The two most widely used models in Missouri are DAMBRK and HEC-1. Recently, private engineers have modified the input structure to the National Weather Service's DAMBRK program, originally developed by Fread (1984). These changes are an attempt to make the model more user friendly and add attractive graphics capabilities. The DAMBRK model considers rapidly varying, unsteady flow in channels and includes off channel storage. It provides an engineer with the most accurate method of simulating a dam failure and routing the flood wave downstream. Despite the capabilities of DAMBRK, the staff of the Dam and Reservoir Safety Program have found that the U.S. Army Corps of Engineers (1981) Hydrologic Engineering Center (HEC) Flood Hydrograph Model (HEC-1) produces reasonable results for dam break analyses.

In order to use HEC-1 to conduct a breach analysis and consider the effects of off-channel storage, the engineer must first rate the channel(s) downstream by performing a backwater analysis. The Corps of Engineers (1985) Water Surface Profile Model (HEC-2) is typically used to perform these computations. As a first estimate, the engineer can use cross sections derived from USGS topographic maps. However, these sections produce results only as reliable as the degree of accuracy of the map. This is normally 10 feet for maps with twenty foot contours and 5 feet for maps with ten foot contours. If additional accuracy is required, surveyed cross sections of the valley must be obtained.

When the channel has been rated for a range of flowrates, the engineer must select the dam failure criteria. The final breach geometry and the time to failure are the two most significant parameters to select. According to Fread (1984), the final breach width should be selected in the range of one to three times the height of the dam, the side slope of the breach should vary from 0-2 horizontal to 1

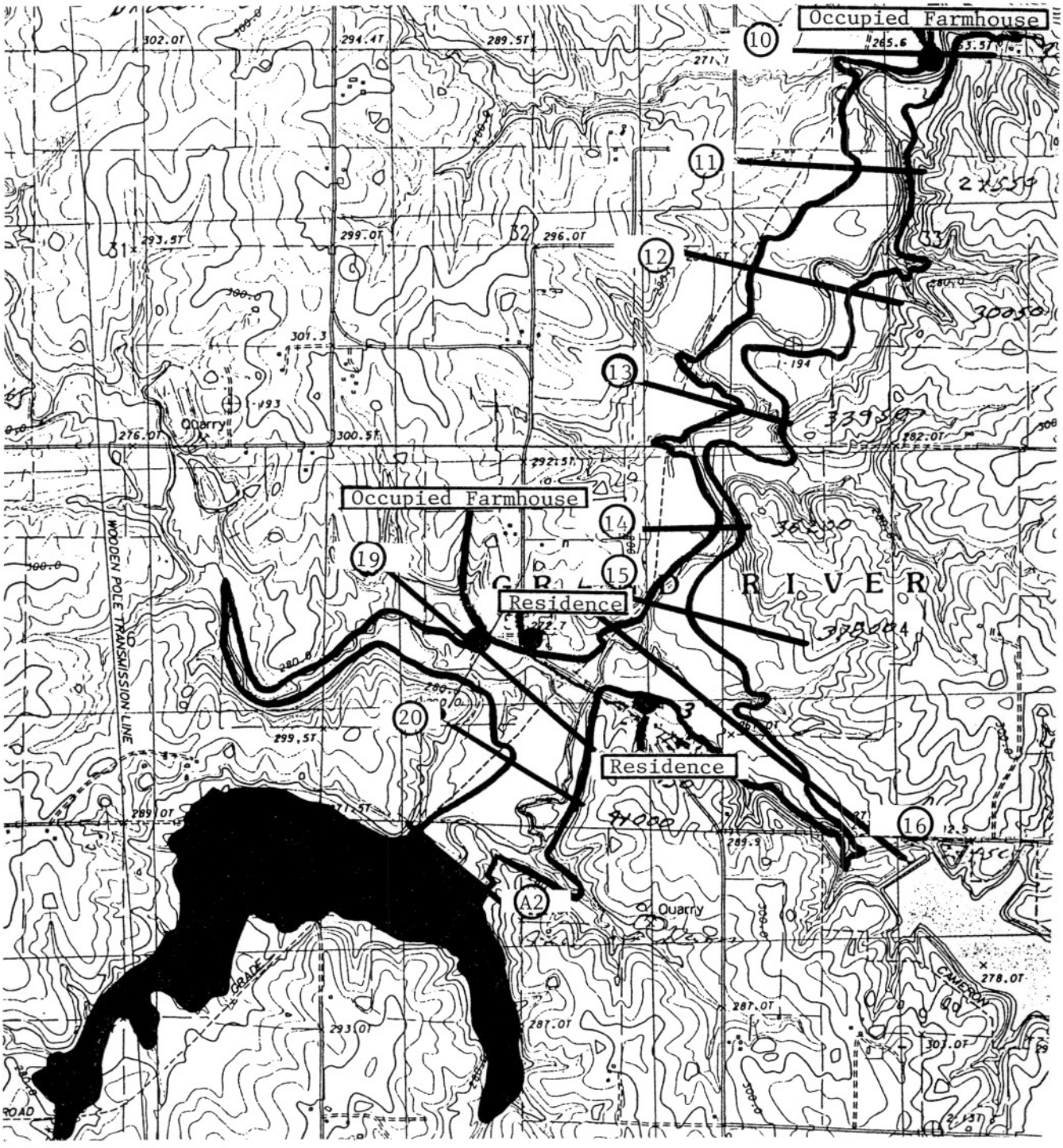


Figure 3.1 Topographic Map of Downstream Environmental Zone

vertical, and the time to breach should be in the range of 0.5 to 4 hours. For concrete gravity and arch dams, the time to breach is typically considered to be 10 minutes or nearly instantaneous. For earth dams, a breach width equal to the height of the dam and a sideslope of 1 horizontal to 1 vertical are normally used unless the dam contains observable geotechnical defects.

Upon completion of the breach analysis, a water surface profile should be drawn of the flood wave created by the failure of the dam. The profile should include the elevation of all homes that would be inundated by the flood wave. When topographic cross sections are used, the profile should also include the estimated elevations of all homes according to the degree of accuracy of the map.

Finally, a topographic map should be submitted as shown in Figure 3.1. It should include the location of the

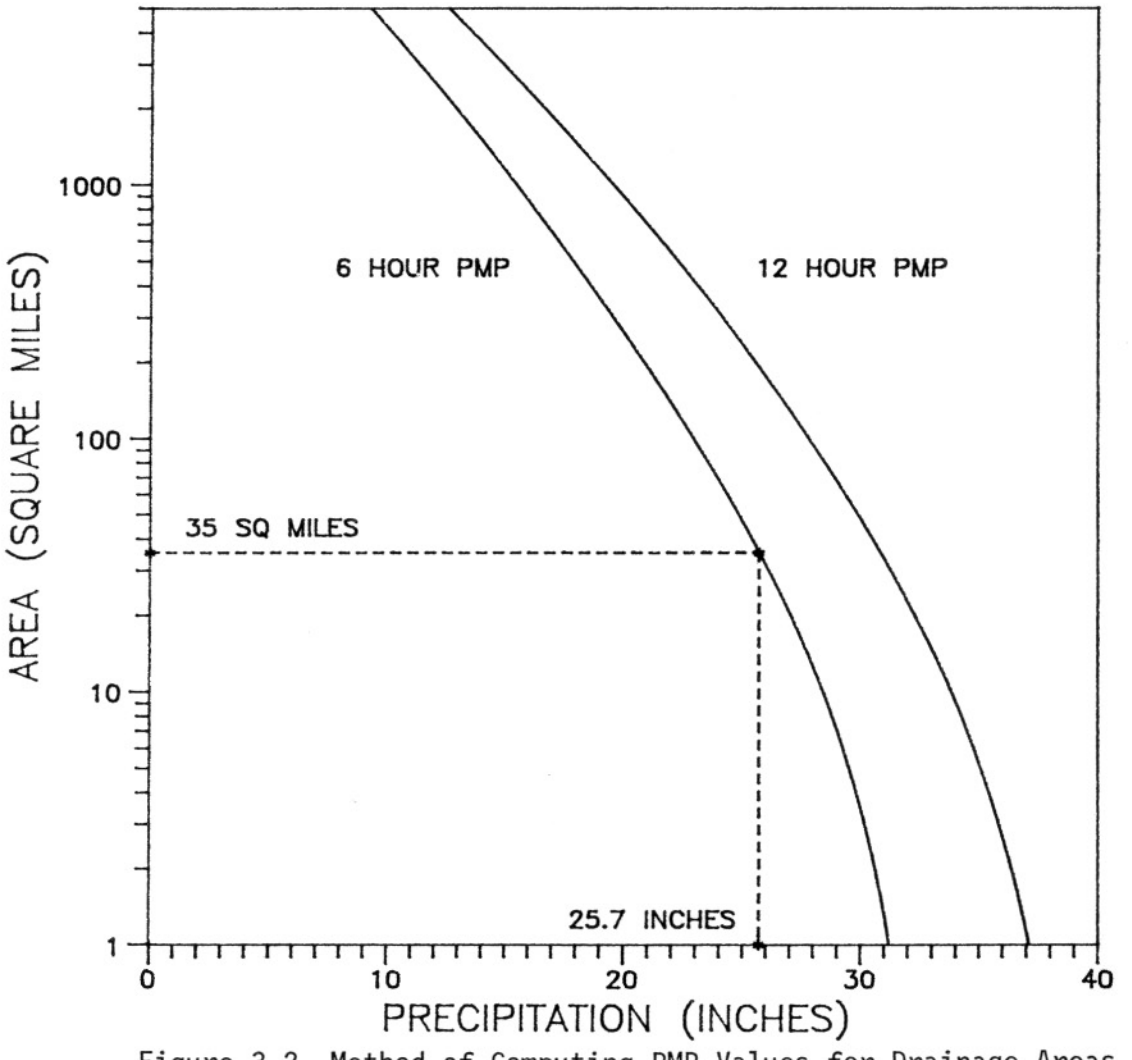


Figure 3.2 Method of Computing PMP Values for Drainage Areas

dam and reservoir, the location of stream cross sections used in the breach analysis, the boundary of the breach floodplain, and verified locations of permanent dwellings, campgrounds, industrial buildings, and public buildings within the breach floodplain. Because the cultural data shown on topographic maps may be several years old, field verification of the information on the map is essential.

B. Spillway Design Flood Precipitation Values

The precipitation values listed in Table 5, 10 CSR 22-3.020, must be used to determine the spillway design flood for both new and existing dams. After the downstream environmental class has been determined, the precipitation value to be used in the hydrologic computations can be selected. The probable maximum precipitation (PMP) can be obtained from Hydrometeorological Report 51, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, published by the U.S. Department of Commerce (1978). This publication contains PMP values for watersheds east of the 105th meridian that range in size from 10 to 20,000 square miles. Rainfall durations range from 6 to 72 hours. The National Weather Service states that "point" PMP values are likely to be greater than the 10 square mile values; however, in performing dam safety analyses, it is acceptable to use the 10 square mile PMP values rather than deriving a PMP value for a smaller area. This procedure is allowed to compensate for the unliklihood that a small watershed will receive the most intense rainfall in any storm. For drainage areas greater than 10 square miles, the engineer has the option of determining the PMP value for the area being considered by using the method shown in Figure 3.2. This method is explained in more detail in Hydrometeorological Report 51.

Several different duration rainfall events must be ana-

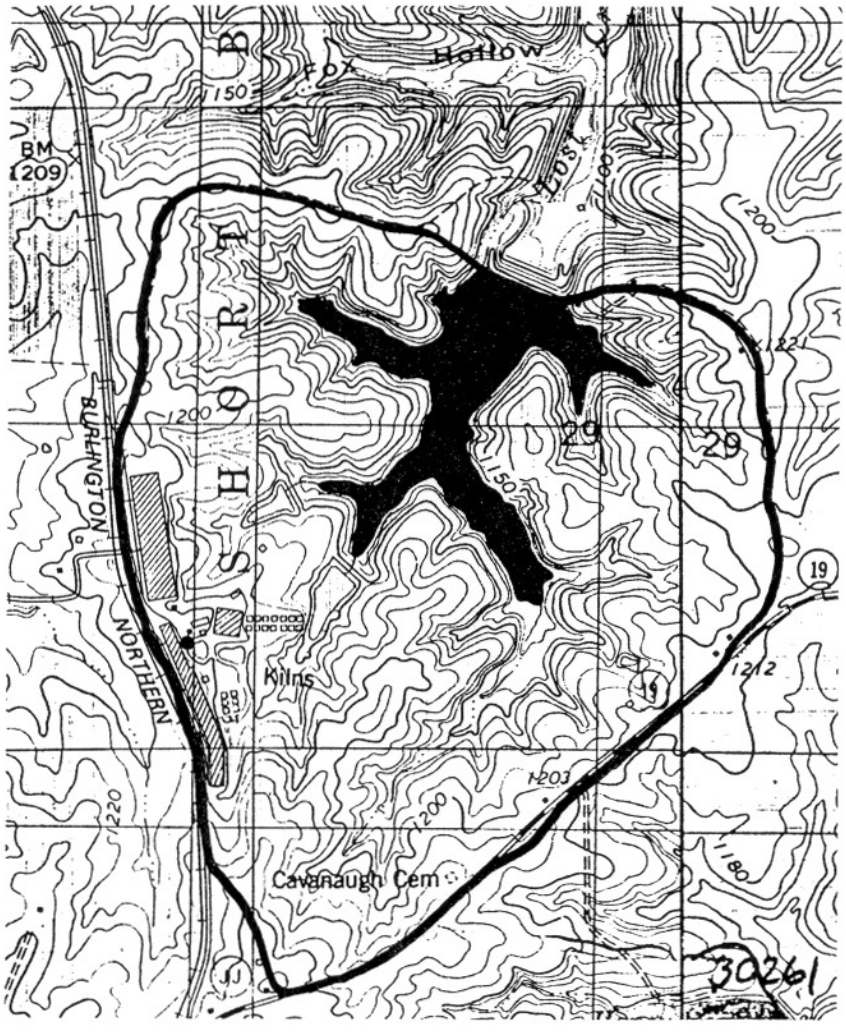


Figure 3.3 Topographic Map of Drainage Area

lyzed. The duration that produces the highest reservoir elevation in the overtopping analysis is termed the critical duration rainfall event. The search for this event is limited to the durations listed in Hydrometeorological Report 51 (6, 12, 24, 48 and 72 hour events). For watersheds less than 1 square mile in size the critical duration event is normally the 6 or 12 hour event.

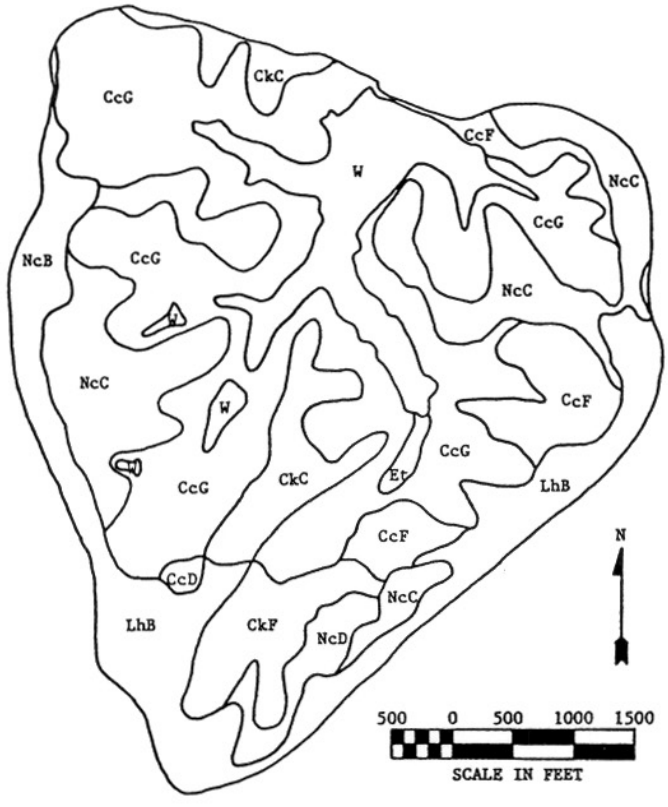
If a grass lined emergency spillway is proposed for a new dam or the modification of an existing dam, it is advisable to design it so that it will only be used for rainfall events in excess of the 50 or 100-year events. Values for these frequency based rainfall events can be found in Technical Paper 40, Rainfall Frequency Atlas of the United States, published by the U.S. Department of Commerce (1961).

Appendix C contains total rainfall values, by county, for 6-hour, 12-hour, and 24-hour frequency based and PMP events in Missouri. The PMP values are for 10 square mile areas only. For other durations, areas, and return periods, engineers should consult Hydrometeorological Report 51 and Technical Paper 40.

C. Watershed Data

All available information concerning watershed characteristics should be assembled. As shown in Figure 3.3, a map of the drainage area should be prepared showing the drainage system, contours, drainage boundaries, and locations of any precipitation stations and streamflow gaging stations. Available data on soil types, cover, and land usage provide valuable guides to judgement and should also be assembled. If the Soil Conservation Service (SCS) has published a soil survey booklet for the county in which the drainage area is located, a soil map can be developed as shown in Figure 3.4. Engineers are advised to contact the county SCS office for a copy of the soil survey booklet.

Land use, such as woodland, pasture, farmland, and



SYMBOL	SOIL TYPE	SLOPE
CcD	Clarksville Cherty Silt Loam	9-14%
CcF	Clarksville Cherty Silt Loam	14-30%
CcG	Clarksville Cherty Silt Loam	30-50%
CkC	Coulstone and Clarksville Cherty Soil	2-9%
CkF	Coulstone and Clarksville Cherty Soil	14-30%
Et	Elsah Certy Loam	1-2%
LhB	Lebanon and Hobson Silt Loam	2-5%
NcB	Nixa-Clarksville Cherty Loam	2-5%
NcC	Nixa-Clarksville Cherty Loam	5-9%
NcD	Nixa-Clarksville Cherty Loam	9-14%
W	Water	

Figure 3.4 Soil Map of Drainage Area

residential can be determined from several sources such as topographic maps, tax reassessment photographs, and Agricultural Stabilization and Conservation Service (ASCS) aerial photographs.

For large watersheds, it is advisable to divide the drainage area into subbasins on the basis of size, drainage pattern, existing and proposed facilities, vegetation, and soil and cover types. The subbasin hydrographs are channel routed downstream to the reservoir. Upstream dams and reservoirs may be included in the analysis. Any upstream dam that is found to overtop during the spillway design flood must either be considered to breach or omitted from the analysis. Breaching is assumed to commence when the reservoir exceeds the lowest elevation on the crest of the dam. The breach hydrograph is then routed downstream and added to the inflow hydrograph at the next reservoir. It is advisable to calibrate the spillway design flood results to historical flood events where adequate stream gage data are available. However, most small watersheds in Missouri are not gaged.

The USGS now has 7 1/2 minute topographic maps for the entire state of Missouri. These can be purchased from commercial businesses or ordered from Department of Natural Resources, Maps and Publications, P.O. Box 250, Rolla Missouri 65401; Phone (314) 364-1752. Watershed and subbasin areas should be determined by use of mechanical planimeters or electronic digitizers. Several area measurements should be taken to determine the value to use in the hydrological computations.

D. Initial Abstraction and Infiltration

Initial abstraction consists of the sum of interception, depression storage, and infiltration which occurs prior to runoff. After runoff begins, infiltration continues throughout the duration of the rainfall event.

Interception and depression storage are intended to represent the surface storage of water by trees, grass, and local depressions in the ground surface. These important hydrologic processes must be carefully considered in models which are used to describe the hydrology of a watershed.

Several empirical infiltration models have been developed but few include procedures for estimating interception and depression storage losses. Recognizing this problem, the SCS (1972) developed the curve number method which can be used to estimate runoff from small agricultural watersheds. In view of the general lack of available data pertaining to abstractions during storm events, the SCS curve number method is used by the staff of the Dam and Reservoir Safety Program to determine both initial abstraction and infiltration losses. If other infiltration models are used, the engineer should estimate the interception and depression storage losses based on a review of available soil and cover data.

In order to use the SCS curve number method to estimate the initial abstraction for a subbasin, an area weighted runoff curve number, CN, should be computed. The factors that determine the runoff curve number are the hydrologic soil group, land use, hydrologic condition and the antecedent moisture condition (AMC).

Hydrologic soil groups have been defined by the Soil Conservation Service (1986) for each of the soils in Missouri. They range from A (most permeable) to D (least permeable). The land use addresses the type of development in the subbasin. Typical values for CN for various land uses are shown in Tables 3.1, 3.2, and 3.3 (SCS, 1986). The hydrologic condition takes into account the effect of cover and is generally estimated from density and type of plant growth. The reservoir area can either be considered as an impervious area in the model or included in the weighted runoff curve number computations.

The antecedent moisture condition (AMC) is classified into three categories by the SCS (1972) depending on the available moisture capacity of the soil. Antecedent moisture condition II is used by the staff of the Dam and Reservoir Program to determine the weighted runoff curve number for a watershed. The values of CN in Tables 3.1, 3.2, and 3.3 are for AMC II conditions.

When the SCS curve number method is used in the HEC-1 model, the initial abstraction is computed for each subbasin by using the empirical relationship (SCS, 1972):

$$I_a = 0.2\left(\frac{1000}{CN} - 10\right) \qquad (3.1)$$

This relationship was developed by the SCS to estimate initial abstraction and is an approximation based upon a scattering of rainfall-runoff data for watersheds less than 10 acres in size.

Infiltration is defined as the entry of water from the surface into the soil profile. It is an important hydrologic process which must be carefully considered in the hydrology of a watershed. Several factors affect infiltration. These include soil properties, the initial water content, rainfall rates, surface sealing and crusting, layered soils, and the porosity of the soil. Many empirical and physical models are available to estimate the infiltration rate.

The SCS method is typically used to determine the infiltration rate after the initial abstraction has been satisfied. Direct runoff is computed by the HEC-1 model in the following manner:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}, \qquad (3.2)$$

where

Q = incremental direct runoff in inches;
P = incremental storm rainfall, in inches; and
S = (1000/CN) - 10.

The actual infiltration in any increment of time is equal to $P - I_a - Q$.

E. Unit Hydrographs

Unit hydrographs are used in the planning and design of water control structures. Chow (1964) defined the unit hydrograph of a drainage basin as a hydrograph of direct runoff resulting from 1 inch of effective rainfall generated uniformly over the basin area at a uniform rate during a specified period of time or duration.

Because most watersheds are ungaged, the use of synthetic unit hydrographs is an accepted procedure in the computation of inflow hydrographs into a reservoir. Synthetic unit hydrographs are based on the assumption that watersheds within a homogeneous region have similar rainfall-runoff characteristics. Although this is not the most accurate procedure to use, the lack of gaged data makes the use of synthetic unit hydrographs necessary.

The two most commonly used synthetic unit hydrograph methods in Missouri are the SCS dimensionless unit hydrograph and Gray's (1961) unit hydrograph. The SCS method is shown in Figure 3.5 and is included in many of the commonly used computer models. It is typically used on small watersheds. According to Technical Release 60 (SCS, 1985), the SCS unit hydrograph is valid on watersheds up to 50 square miles in size. Larger watersheds should be divided into subbasins with areas less than 20 square miles. Gray's method was developed using data for the midwestern United States. This unit hydrograph is applicable for watersheds up to 94 square miles. Both methods are acceptable for dam safety analysis.

TABLE 3.1

Runoff Curve Numbers - Urban Areas

Cover Description Cover type and hydrologic condition[1]	Ave % Impervious[2]	Curve Numbers[3] for Hydrologic Soil Group A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc):					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved streets, roads, parking lots, roofs, driveways, etc.	100	98	98	98	98
Paved; open ditches (including right of way)		83	89	92	93
Gravel (including right of way)		76	85	89	91
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82

[1]Average runoff condition, and $I_a = 0.2S$.

[2]The average percent impervious area shown was used to develop the composite CN's.

[3]AMC II conditions.

TABLE 3.2

Runoff Curve Numbers - Agricultural Lands[1]

Land use	Treatment or Practice[2]	Hydrologic Condition[3]	Curve Numbers[4] for Hydrologic Soil Group A	B	C	D
Fallow	Bare soil	----	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
	Crop residue cover (CR)	Good	74	83	88	90
Row Crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Straight row & CR	Poor	71	80	87	90
	Straight row & CR	Good	64	75	82	85
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured + CR	Poor	69	78	83	87
	Contoured + CR	Good	64	74	81	85
	Contoured + terraces	Poor	66	74	80	82
	Contoured + terraces	Good	62	71	78	81
	Contoured + terraces + CR	Poor	65	73	79	81
	Contoured + terraces + CR	Good	61	70	77	80
Small Grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Straight row & CR	Poor	64	75	83	86
	Straight row & CR	Good	60	72	80	84
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured + CR	Poor	62	73	81	84
	Contoured + CR	Good	60	72	80	83
	Contoured + terraces	Poor	61	72	79	82
	Contoured + terraces	Good	59	70	78	81
	Contoured + terraces + CR	Poor	60	71	78	81
	Contoured + terraces + CR	Good	58	69	77	80

[1]Average runoff condition, and $I_a = 0.2S$.

[2]Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

[3]Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetation, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good $\geq$ 20%), and (e) degree of surface roughness.

Poor:Factors impair infiltration and tend to increase runoff.

Good:Factors encourage average and better than average infiltration and tend to decrease runoff.

[4]AMC II conditions

TABLE 3.3

Runoff Curve Numbers - Noncultivated Agricultural Lands

Cover Type	Hydrologic Condition[1]	Curve Numbers[2] for Hydrologic Soil Group			
		A	B	C	D
Pasture, grassland, or range-continuous forage for grazing[3]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow--continuous grass, protected from grazing and generally mowed for hay	----	30[4]	58	71	78
Brush--brush-weed-grass mixture with brush the major element.[5]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods--grass combination (orchard or tree farm)[6]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[7]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads-buildings, lanes, driveways, and surrounding lots.	----	59	74	82	86

[1]Average runoff condition, and $I_a = 0.2S$.

[2]AMC II conditions

[3]Poor; <50% ground cover or heavily grazed with no mulch.
Fair; 50% to 75% ground cover and not heavily grazed.
Good; >75% ground cover and lightly or only occasionally grazed.

[4]Actual curve number is less than 30; use CN=30 for runoff computations.

[5]Poor; <50% ground cover.
Fair; 50% to 75% ground cover.
Good; >75% ground cover.

[6]CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[7]Poor; Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair; Woods are grazed but not burned, and some forest litter covers the soil.
Good; Woods are protected from grazing, and litter and brush adequately cover the soil.

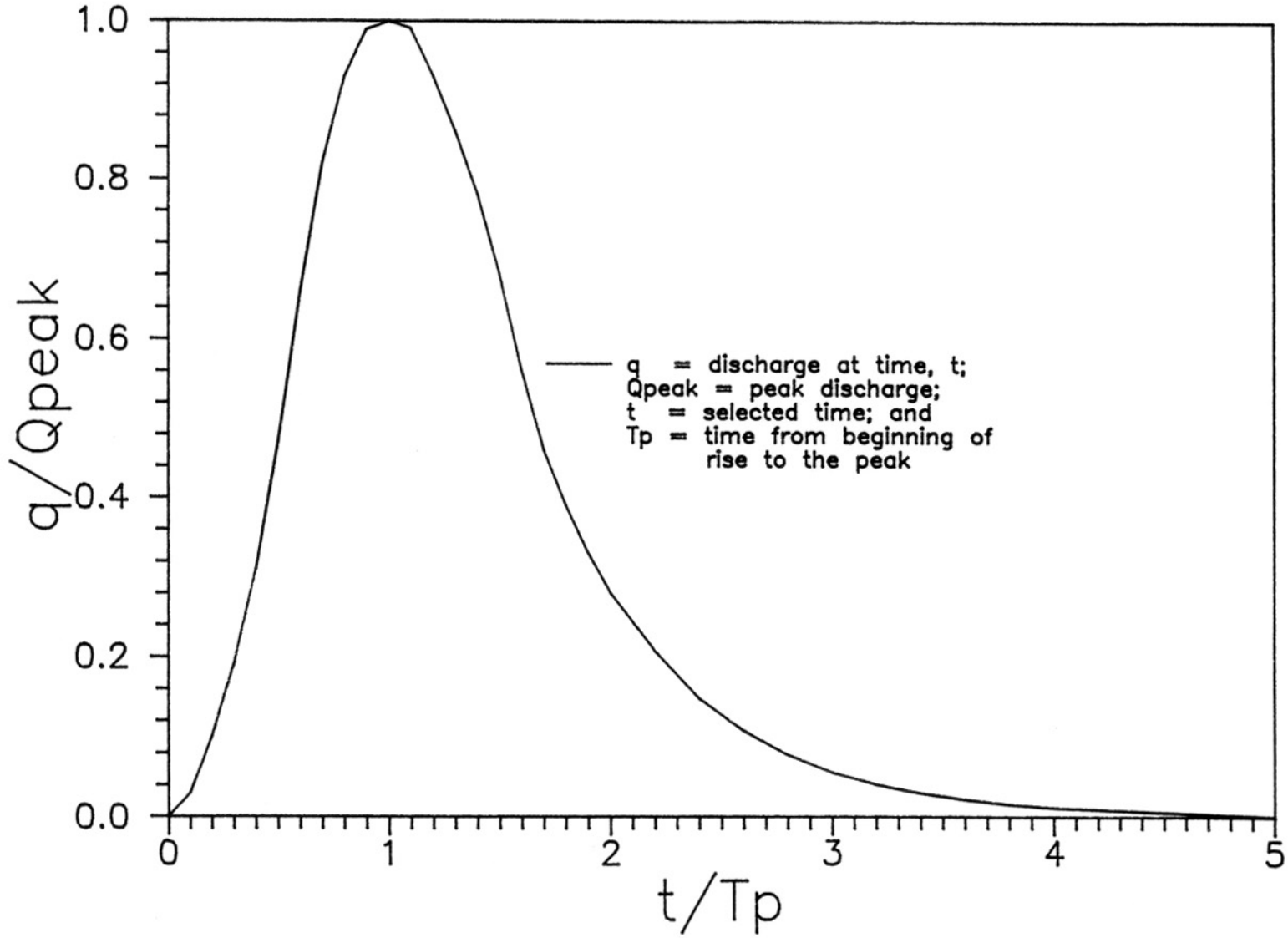


Figure 3.5 SCS Dimensionless Unit Hydrograph

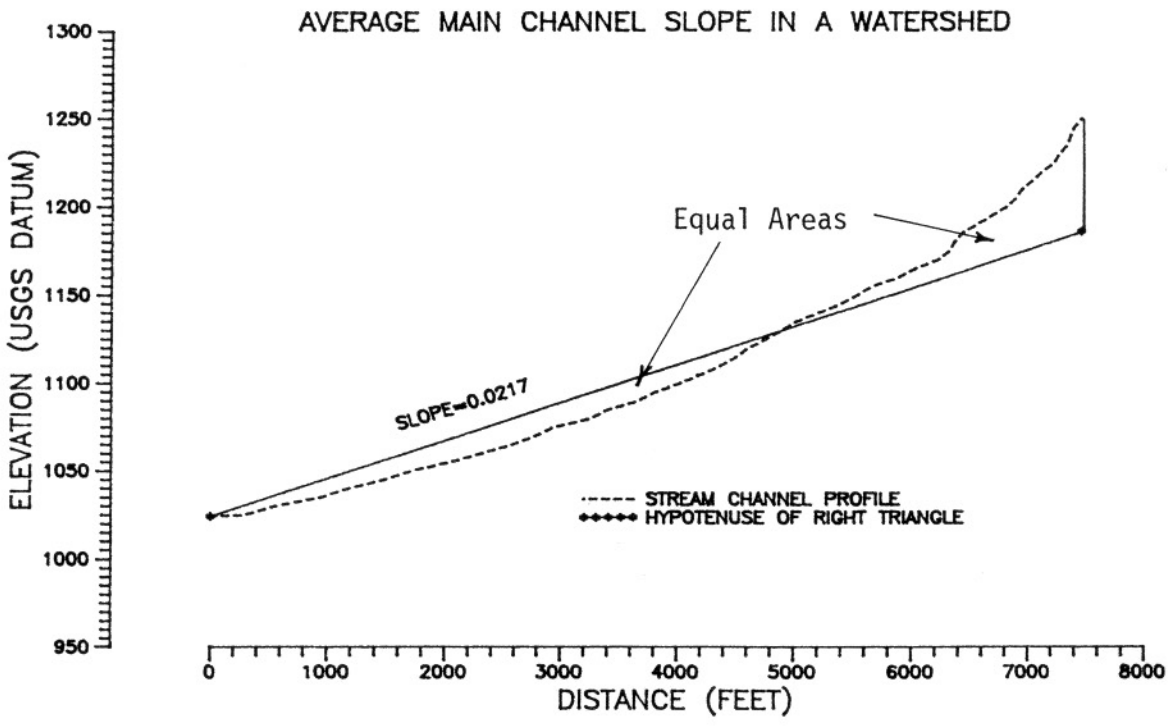


Figure 3.6 Gray's (1961) Method of Computing Channel Slope

The SCS dimensionless unit hydrograph is based upon empirical observations of how natural watersheds "typically" respond to rainfall in excess of the rate at which it can infiltrate. A good description of the method is included in the SCS (1972) National Engineering Handbook, Section 4, Hydrology. The basic input parameters needed to develop a synthetic unit hydrograph for a watershed include the basin lag time, basin area, and the duration of the unit hydrograph. Time to peak, T_P, and the peak flow, Q_{peak}, for each increment of rainfall are computed from these three parameters.

The basin lag time, T_L, should be computed before the unit hydrograph duration, ΔD, is specified. The SCS dimensionless unit hydrograph is based on the relationship, $\Delta D = 0.22T_L$. According to the SCS, a small variation in ΔD is permissible, however, ΔD should not be greater than 0.25 T_P. This SCS guideline lead the Corps of Engineers to recommend the relationship in Equation 3.3 for selecting the HEC-1 computation interval, Δt.

$$\Delta t \leq .29T_L, \qquad (3.3)$$

where

Δt = HEC-1 computation interval in minutes; and

T_L = basin lag time in minutes.

Selection of the HEC-1 computation interval is very important because it is also the duration of the SCS dimensionless unit hydrograph.

In Gray's unit hydrograph, a gamma distribution is used to describe a dimensionless unit hydrograph. The length and slope of the main channel upstream of the reservoir and the watershed area are the parameters used to develop the synthetic unit hydrograph. These parameters can easily be obtained from a topographic map. Channel slope is determined as shown in Figure 3.6. The area beneath the channel profile is set equal to the area of a right triangle with the hypotenuse crossing the origin at the elevation of the reservoir. The slope of the hypotenuse is the average channel slope. Gray's unit hydrograph can be computerized to solve for the Unit Hydrograph Ordinates based on an input of watershed area, channel length, and channel slope. A good description of the method is presented by Viessman, Harbaugh, and Knapp (1972).

F. Time of Concentration

The use of synthetic unit hydrographs requires a characterization of watershed response time. This characteristic time is usually taken to be either time of concentration or basin lag time. Both are commonly assumed to be constant and lag time is often considered to be a fraction

of time of concentration so that one is easily converted to the other. Lag time must be computed in order to use the SCS dimensionless unit hydrograph. With Gray's unit hydrograph, the time of concentration is implicitly computed in the determination of the hydrograph ordinates.

The SCS (1972) defined lag time as the time interval between the centroid of effective rainfall and the peak of direct runoff. When used with the SCS unit hydrograph, this definition assumes that lag time is stable and is constant regardless of rainfall duration or intensity. This assumption of linearity is made to simplify computations. Based on their experience on small watersheds, the SCS estimates lag time as

$$T_L = 0.6T_c, \tag{3.4}$$

where

T_C = time of concentration in minutes.

A number of empirical approaches to estimating basin response time have come to be accepted in the field of hydrology for dam safety. Among the most common are the Kirpich formula (1940), the Kerby-Hathaway formula (Kerby, 1959), the SCS Upland method, and the SCS Lag method (SCS, 1985). The SCS methods and the Kerby-Hathaway method consider surface roughness and all four methods recognize the importance of length and slope of the flow path. None of these methods, however, reflect the influence of rainfall characteristics such as rainfall duration and intensity.

The Kirpich formula was developed from data gathered by Ramser (1927) from experiments conducted on a single 112 acre agricultural watershed in Tennessee. The equation is

$$T_c = 0.00013L^{.77}S^{-.385}, \tag{3.5}$$

where

T_C = time of concentration in hours;
L = length of the watershed in feet; and
S = slope in feet/feet.

A version of the Kirpich formula is printed in the U. S. Department of of the Interior (1974) manual entitled Design of Small Dams.

The SCS Lag method is shown in Equation 3.6 and is based on the assumption that the time of concentration equals 1.67 times the lag time. It can be used on watersheds up to 2000 acres in size.

$$T_c = 0.000879L^{.8}\left(\frac{1000}{CN} - 9\right)^{.7} Y^{-.5}, \tag{3.6}$$

where

T_C = time of concentration in hours;
L = hydraulic length of the watershed in feet;
CN = hydrologic soil cover complex no.; and
Y = average watershed land slope, %.

The slope in Equation 3.6 is the average land slope, not the channel slope. It is typically computed from topographic maps and SCS soil survey maps. Horton (1932) published three methods of computing overland slope which are frequently used. These include the contour area method, the mean slope method, and the intersection line method.

The contour area method requires that areas be planimetered between each successive pair of contour lines in a subbasin. Each area is divided by the average contour length for the interval being considered to compute the average distance between contours as shown in Equation 3.7.

$$L_i = \frac{A_i}{\frac{L_1 + L_2}{2}}, \tag{3.7}$$

where

L_i = average distance between contours;
A_i = intermediate area;
L_1 = length of first contour; and
L_2 = length of second contour.

The overland slope of the subbasin is then computed as

$$S_o = \sum \frac{(A_i D)}{A_T L_i}, \tag{3.8}$$

where

S_O = overland flow slope;
D = contour interval; and
A_T = subbasin area.

The mean slope method is a simplified form of the contour area method because it considers the subbasin as a whole. The total length of contours in the subbasin is determined and the mean slope is computed by Equation 3.9.

$$S_o = \frac{D\sum L}{A_T}, \tag{3.9}$$

where

$\sum L$ = total length of contours.

According to Horton (1932), the mean slope method gives good results if the relief is moderate and contours are spaced uniformly.

An average watershed slope can also be computed by weighting the average slopes from the SCS soil map shown in Figure 3.4.

The SCS (1985) Upland Method, shown in Equation 3.10, was developed primarily for flow in upland areas which include overland flow and flow through grassed waterways, paved areas, and small upland gullies.

$$T_c = \frac{L}{3600V}, \qquad (3.10)$$

where

T_C = time of concentration in hours;
L = channel length in feet; and
V = velocity of full bank flow in feet/second.

Travel times for each mode of upland flow and land use are computed from a graph of experience curves (SCS, 1972) showing velocity versus slope for various ground cover conditions. The summation of these travel times equals the time of concentration in the watershed. This method is limited to watersheds less than 2000 acres.

Huggins and Burney (1982) suggested computing time of concentration by adding the channel travel time from the Kirpich equation and the overland flow travel time from the Kerby-Hathaway equation. The basis for the Kerby-Hathaway formula, shown in Equation 3.11, is a study conducted by Hathaway (1945) on overland flow for airfield design and construction.

$$T_c = 0.01377\, L_o^{.47} n^{.47} S_o^{-.235}, \qquad (3.11)$$

where

T_C = time of concentration in hours;
L_O = overland flow length;
n = roughness factor; and
S_O = overland flow slope in feet/feet.

When using this method, overland flow lengths should be limited to 500 feet. The roughness factor, n, has the same meaning for overland flow as it does for channel flow, but it is typically higher (0.1 - 0.4) due to the combined resistance effects of the overland flow surface. Kerby (1959) suggested the following values:

TYPE OF SURFACE	n
Smooth impervious surface	.02
Smooth, bare, packed soil	.10
Poor grass, cultivated row crops, or moderately rough bare surface	.20
Pasture or average grass	.40
Deciduous timberland	.60
Conifer timberland, deciduous timberland with deep forest litter, or dense grass	.80

Engman (1986) analyzed data from experimental plots and recommended roughness coefficients of 0.13 for range grass, 0.24 for dense grass, 0.41 for Bermuda grass and 0.45 for bluegrass sod.

This last method, which combines the time of concentration values obtained from the Kirpich and Kerby-Hathaway formulas, is the method generally used by the staff of the Dam and Reservoir Safety Program.

All four methods are acceptable for dam safety analysis, but none of them consider the affects of rainfall. Swenty (1989) conducted a study which showed that lag time is affected by rainfall duration, depth, and intensity. He concluded that the traditional approach of combining the overland and channel flow lag times from the Kerby-Hathaway and Kirpich equations yields reasonable estimates of basin lag time for 100% PMP events on basins less than 1 square mile in size. All four methods were found to underestimate basin lag time for 6-hour and 12-hour rainfall events, less than the 100% PMP.

G. Rainfall Hyetographs

In order to compute an inflow hydrograph, the spillway design flood precipitation value must be distributed over the duration of the rainfall event. Methods are included in the SCS (1974) National Engineering Handbook No. 4 (NEH-4), the U. S. Department of the Interior (1974) Design of Small Dams, and the U. S. Army Corps of Engineers (1987) Flood Hydrograph Package, HEC-1, but the distributions used by the Dam and Reservoir Safety Program are those developed by Huff (1980). Huff published four rainfall distributions for various duration rainfall events. The data used to derive these rainfall distributions were acquired from gaging stations in the state of Illinois. Because of Missouri's close proximity to Illinois, these distributions are acceptable for dam safety projects in Missouri.

The average time distribution of heavy rainfall at a point is shown in Table 3.4 (Huff, 1980). Huff recommended that the point time-distribution relationships shown in Table 3.4 be used with PMP rains extending from a point to 50 square miles.

First and second quartile rainfall distributions should be used for rainfall events less than 12 hours, third quartile rainfall distributions should be used for rainfall durations of 12 to 24 hours and fourth quartile rainfall distributions would be used for rainfall durations greater than 24 hours. Distributions for areas from 50 to 400 square miles were also derived by Huff (1980).

Huff's distributions can also be used to distribute the 50-year and 100-year rainfall events. These rainfall events are typically used to design emergency spillways and to analyze the affect of proposed spillway modifications on discharge rates.

H. Inflow Hydrograph Computation

The inflow design flood hydrograph represents direct runoff from precipitation in the form of rain over a watershed. If hand computations are performed, the procedure outlined in Table 3.5 is recommended.

This procedure should be followed for each duration rainfall event that is analyzed. For a typical small watershed, both a 6-hour and a 12-hour inflow hydrograph will have to be computed. Larger watersheds will require the analysis of longer duration events.

TABLE 3.4 Median Time Distributions of Heavy Storm Rainfall at a Point

Cumulative storm rainfall (percent) for given storm type

Cumulative storm time (percent)	First-quartile	Second-quartile	Third-quartile	Fourth-quartile
5	16	3	3	2
10	33	8	6	5
15	43	12	9	8
20	52	16	12	10
25	60	22	15	13
30	66	29	19	16
35	71	39	23	19
40	75	51	27	22
45	79	62	32	25
50	82	70	38	28
55	84	76	45	32
60	86	81	57	35
65	88	85	70	39
70	90	88	79	45
75	92	91	85	51
80	94	93	89	59
85	96	95	92	72
90	97	97	95	84
95	98	98	97	92

TABLE 3.5

Procedure for Computing an Inflow Hydrograph

Step 1	Determine the size of the drainage area of each basin for which an inflow hydrograph is to be computed.
Step 2	For watersheds less than 10 square miles, determine the PMP values for 6-hour, 12-hour and 24-hour events. For larger watersheds, adjust the PMP value as described in Section B and include 48-hour and 72-hour duration events.
Step 3	Compute the time of concentration for the drainage basin and convert to lag time.
Step 4	Using the lag time, compute the computational time interval, Δt, where $\Delta t \leq 0.29$(lag time).
Step 5	Determine the downstream environmental zone and select the appropriate design precipitation value from Table 5, 10 CSR 22-3.020.
Step 6	Determine the rainfall hyetograph by using Huff's Quartile distributions in Table 3.3. Sum the ordinates to compute an accumulative design rainfall table.
Step 7	Determine the initial abstraction and construct an infiltration model for the watershed. Compute the amount of excess rainfall at each time step. If the SCS curve number method is used, determine the hydrologic soil cover complex number, CN, of the watershed and perform steps 8 and 9.
Step 8	Determine the accumulative direct runoff from Equation 3.2.
Step 9	Convert the accumulative direct runoff table to an incremental table of direct runoff.
Step 10	Construct a synthetic unit hydrograph for the basin.
Step 11	Compute hydrographs for each time increment using the synthetic unit hydrograph (step 10) and either the excess rainfall at each time step (step 7) or the incremental table of direct runoff (step 9). Overlay hydrographs and add ordinates at each time increment. The summation of all ordinates produces the inflow hydrograph to the reservoir.

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Page 18, Table 3.5, Step 6, should read,

Determine the rainfall hyetograph by using Huff's Quartile distributions in Table 3.4. Sum the ordinates to compute an accumulative design rainfall table.

Page 20, definition of term D_{rc} in second column should read,

D_{rc} = diameter of riser in ft.

Page 24, Table 4.1 should read,

TABLE 4.1

Geometric Elements of Trapezoidal Channels

Geometric Element	Symbol	Definition	Equation
Water Area	A	Cross sectional area of the flow normal to the direction of flow	$(b+zy)y$
Wetted Perimeter	P	Length of the line of intersection of the channel wetted surface with a cross sectional plane normal to the direction of flow.	$b+2y\sqrt{1+z^2}$
Hydraulic Radius	R	Ratio of the water area to its wetted perimeter.	$\frac{(b+zy)y}{b+2y\sqrt{1+z^2}}$
Top Width	T	Width of the channel section at the free surface.	$b+2zy$
Hydraulic Depth	D	Ratio of the water area to the top width.	$\frac{(b+zy)y}{b+2zy}$
Section Factor	Z	Product of the water area and the square root of the hydraulic depth.	$\frac{[(b+zy)y]^{1.5}}{\sqrt{b+2zy}}$

Note y = depth of flow in channel

b = channel base width.

z = sideslope of channel, z:1.

Page 29, the conic method equation in column two should read,

The conic method can be used to compute reservoir volume from surface area versus elevation data as follows:

$$\Delta Vol = \frac{(E_{n+1} - E_n)}{3}(A_n + A_{n+1} + \sqrt{A_n A_{n+1}})$$

Page 35, Figure 5.4

"Relief wall" should be "Relief well"

CHAPTER IV

HYDRAULIC CONSIDERATIONS

The hydraulic calculations that are performed in a dam safety analysis involve the principles of fluid mechanics, and the laws of continuity, conservation of momentum, and specific energy. Many dams have a combination of closed conduit spillways, open channel spillways, and gates and valves for water supply and other uses. It is important that the engineer be familiar with the principles of hydraulic engineering in order to determine the capacity of these spillways.

After the spillways are rated, an overtopping analysis can be conducted. In order to perform an overtopping analysis, the inflow hydrograph must be routed through the reservoir to determine the maximum water surface elevation during the spillway design flood (SDF). This information not only determines whether a dam can safely pass the SDF; it also defines the maximum reservoir loading condition for the slope stability analysis. The purpose of this section is to provide the engineer with the techniques commonly employed by the staff of the Dam and Reservoir Safety Program to perform these computations.

A. Closed Conduit Hydraulics

Closed conduit spillways can either be single structures, such as culverts, or systems consisting of an inlet structure, a closed discharge pipe and an outlet structure. One advantage of this type of spillway is that near maximum capacity is attained at relatively low heads. This characteristic makes the spillway ideal for use where the maximum spillway outflow is to be limited. A disadvantage of conduit spillways is that there is little increase in capacity at higher reservoir levels.

1. Design Considerations for Conduit Spillways

On new dams and modifications to existing dams, the inlet structure should be designed to establish full pipe flow at as low a head as practical and to operate without excessive surging, vibration, or vortex action. This requires the inlet to have a larger cross-sectional area than the main conduit or ventilation.

Trash racks should be placed on inlet risers to exclude trash too large to pass freely through the spillway and outlet structure. General criteria for trash racks is included in the booklet, Maintenance, Inspection, and Operation of Dams in Missouri.

Conduits under earth embankments must support the external loads with an adequate factor of safety. They must withstand the internal hydraulic pressure without leakage under full external load and settlement and convey water at the design velocity without damage to the interior surface of the conduit. The material used for the conduit should be determined by the size of the dam, the economic life of the dam, and the relative ease of replacement.

Conduits should be designed and constructed to remain watertight under maximum anticipated hydrostatic head and maximum joint extension. The analysis should include the effects of joint deflection caused by settlement of the embankment. Corrugated metal pipes are not recommended for use in dams because banded joints are not designed for high pressure flow.

Piping and seepage control around the conduit is an important consideration. For many years, anti-seep collars were required on conduits passing through earth embankment dams. Although no longer used in all dams, anti-seep collars are still an acceptable method for seepage control. When used, the anti-seep collars should be designed to extend the seepage path by 15 percent through the saturated zone. The major disadvantage of anti-seep collars is that it is difficult to compact soil directly against the concrete structure. A large amount of hand compaction is required. An alternative to anti-seep collars is a granular diaphram (sand filter) around a section of conduit downstream of the core. This method is frequently used by the SCS (1986) and is becoming widely accepted by private engineers.

When spillway flows drop from the reservoir pool level to the downstream outlet channel level, the static head is converted to kinetic energy. This energy manifests itself in the form of high velocities, which, if not impeded, results in erosion. Means of returning the flow to the river without serious scour or erosion to the toe of the dam or damage to adjacent structures must be provided. Types of outlet structures include cantilever outlets combined with plunge pools, Saint Anthony Falls (SAF) basins, and impact basins.

2. Shaft Spillways

A shaft spillway is an uncontrolled spillway in which the water enters over a weir and drops through a vertical or sloping shaft into a conduit which discharges into the downstream channel.

The drop-inlet and the morning-glory are the two most common shaft spillways. The drop-inlet spillway is normally a concrete cast-in-place box or a circular sharp crested weir constructed from precast concrete pipe. Figure 4.1 shows a profile of a drop inlet spillway. The morning-glory spillway is a special case of the circular sharp crested weir in which the shape of the weir crest and the upper portion of the shaft are designed to follow the trajectory of the lower nappe.

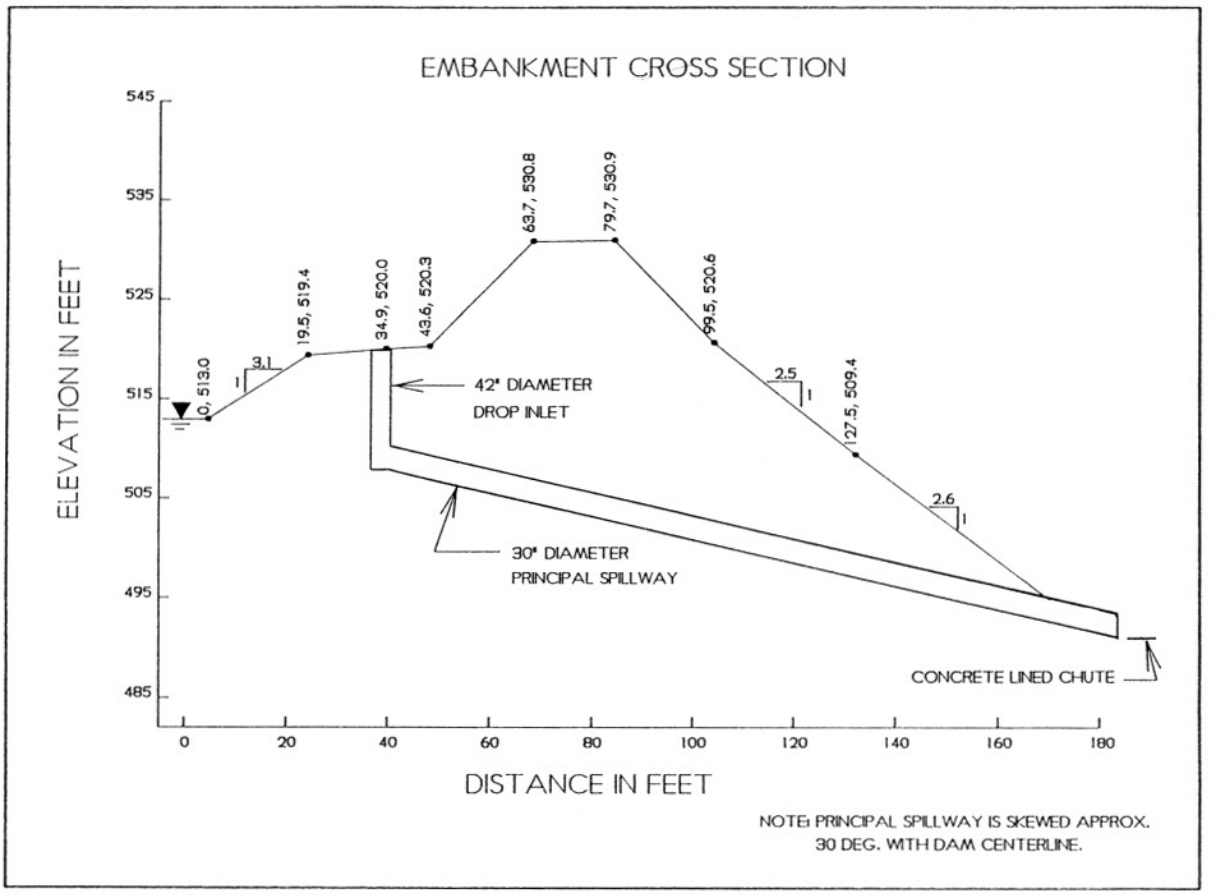


Figure 4.1 Profile of a Drop Inlet Spillway

This section discusses the hydraulic characteristics and the design for a drop-inlet spillway. A discussion of the morning-glory spillway can be found in Design of Small Dams.

The discharge characteristics of a shaft spillway are determined by that portion of the structure which is controlling the discharge. It can be seen in Figure 4.2 that there is the potential for as many as three separate controls and thus three distinct sections in the elevation discharge curve.

The first form of control is weir flow which is described by the weir equation:

$$Q = C_w L_w H^{1.5}, \qquad (4.1)$$

where

Q = discharge in cfs;
C_W = weir coefficient;
L_W = perimeter length of weir in ft.; and
H = depth of water over the weir in ft.

The Portland Cement Association (1964) list the following equations for determining the weir coefficient, C_W, for rectangular drop inlets as a function of the level of the reservoir and the diameter of the outlet pipe:

$$C_w = 3.38\left(1 - \frac{1}{250\frac{H}{D}}\right)^{1.5} \; for \; \frac{Q}{D^{2.5}} < 4, \qquad (4.2)$$

$$C_w = 4.1\left(1 - \frac{1}{16.7\frac{H}{D}}\right)^{1.5} \; for \; \frac{Q}{D^{2.5}} > 4, \qquad (4.3)$$

where

H = headwater depth above the inlet in ft.; and
D = diameter of the outlet pipe in ft.

The weir coefficient, C_W, for circular drop inlets is given in Equation 4.4:

$$C_w = 3.60\left(1 - \frac{0.013}{H/D_{rc}}\right)^{1.5}, \qquad (4.4)$$

where

D_{rc} = diameter or riser in ft.

The transition point between weir and orifice flow occurs when the contraction of the flow is fully developed

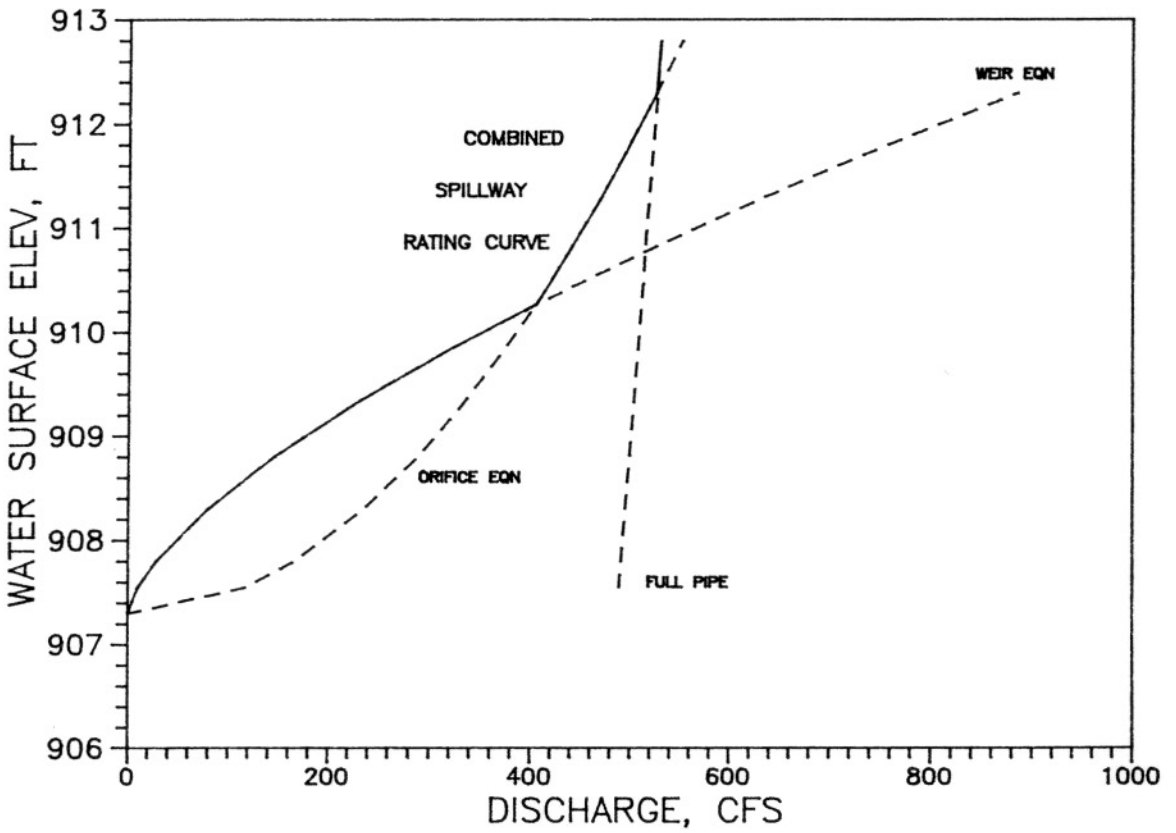


Figure 4.2 Combined Spillway Rating Curve for a Conduit Spillway

at the inlet. The second form of control that must be considered is orifice flow which is discribed in Equation 4.5:

$$Q_o = C_o A\sqrt{(2gH)}, \qquad (4.5)$$

where

Q_O = discharge in cfs;
C_O = contraction coefficient;
A = cross sectional area of inlet in ft^2; and
H = head in feet.

The head is normally taken to be the elevation difference between the top of the inlet and the reservoir surface.

When the depth of water in the vertical riser is above the critical depth for weir flow, the drop inlet will be submerged. Flow is then determined by the relationship in Equation 4.6:

$$Q_p = A_p\sqrt{\frac{2gH_t}{K_c + K_o + \frac{fL}{D}}}, \qquad (4.6)$$

where

Q_p = discharge through pipe in cfs;
A_p = cross sectional area of pipe in square ft;
H_t = total head measured from the headwater surface in the riser to the crown of the pipe outlet in ft;
K_C = total entrance losses, dimensionless coefficient;
K_O = total outlet losses, dimensionless coefficient;
f = Darcy-Weisbach friction factor;
L = length of pipe in feet; and
D = diameter of pipe in feet.

This equation ignores the effect of friction in the riser which, for short risers, is insignificant. Loss coefficients for expansions, contractions, bends, gates, and trashracks are contained in Design of Small Dams. Simon (1986) also provided a good discussion of various loss coefficients.

Figure 4.3 contains a form that can be used to tabulate flow rates under weir, orifice, and full pipe flow conditions. Q_{TOTAL} is determined at each elevation bt taking the minimum of Q_W, Q_O, and Q_P.

This section has not included siphon flow. Unless properly designed to withstand negative pressures, a conduit can be severely damaged by repeated occurrences of siphon flow. A brief explanation of siphon flow follows.

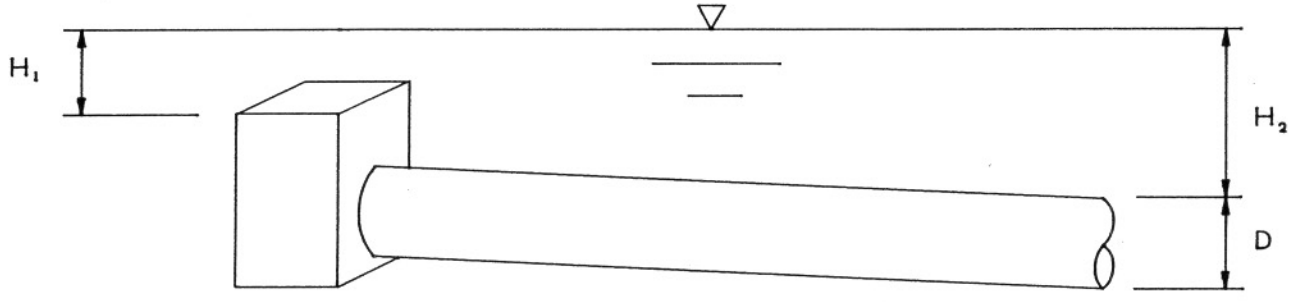
When air is purged from the discharge conduit, large, nearly instantaneous increases in the discharge occur. As the inlet becomes submerged, the high turbulence at the base entrains air and removes portions of the trapped air from the inlet. The pressure inside the inlet becomes negative and creates a pressure differential across the inlet. This is turn increases the discharge through the inlet. The

NAME OF DAM _____ DATE _____

(MO) COUNTY _____ ENGR _____

PIPE CALCULATIONS

ELEV.	H_1	Q_w	Q_o	H_2	Q_p	Q_{Total}



Weir Flow

$$Q_w = C_w L_w H_1^{1.5}$$

Orifice Flow

$$Q_o = C_o A_o \sqrt{2gH_1}$$

Full Pipe Flow

$$Q_p = A_p \sqrt{\frac{2gH_2}{\sum k + \frac{fL}{D}}}$$

C_w = _____ weir coefficient
L_w = _____ weir length of inlet, ft.
H_1 = _____ reservoir elev - inlet elev, ft
C_o = _____ orifice coefficient
A_o = _____ cross sectional area of inlet, ft^2
H_2 = _____ total head at pipe outlet, ft
$\sum k$ = _____ summation of inlet, bend and outlet losses
f = _____ Darcy Weisbach friction factor
A_p = _____ cross sectional area of pipe, ft^2
D = _____ diameter of pipe, ft^2
L = _____ length of pipe, ft

VALUES USED IN ANALYSIS

C_W =
L_W =
H_1 =
C_O =
A =
H_2 =
K =
f =
A_P =
D =
L =

Figure 4.3 Conduit Spillway Calculation Form

increased discharge causes the driving head (the depth of water in the inlet) to increase and increases the discharge through the outlet conduit. During this process the unsteady nature of the flow causes waves to travel down the conduit. Usually a wave will seal the conduit. The large negative pressure created by the wave will cause the system to siphon and flow full. The discharge increases abruptly as the flow jumps from inlet to outlet control. Dynamic pressures are created throughout the system. Unless the reservoir rises rapidly, vortexes and other disturbances at the inlet will bring air into the system, break the siphon, and start the cycle over.

Sometimes the siphon action only partially occurs. As the system begins to siphon, the driving head is drawn down in the inlet. The wave, which had sealed the conduit, allows air back up the conduit. The driving head quickly rises and forces the trapped air in the inlet up and through the top "belching" out into the atmosphere. The water at the inlet quickly replaces the belched air as it passes out, and falls into the inlet as a slug causing dynamic pressure surges. These surges can cause damaging vibration throughout the system. Measures must be taken to avoid this problem and insure the proper operation of the system.

3. Culvert Spillways

A culvert spillway ordinarily consists of a simple culvert conduit placed through the dam or along the abutment, generally on a uniform grade with the entrance placed vertically or inclined. The culvert cross section may be round, rectangular, square, or some other shape. Usually, prefabricated pipe materials such as concrete or PVC are utilized.

The factors which combine to determine the nature of flow in a culvert spillway include slope, size, shape, length, roughness of the conduit barrel, and the inlet and outlet geometry. The combined effect of these factors determines the location of the control which in turn determines the discharge characteristics of the conduit. The location of the control dictates whether the conduit flows partly full or full and thereby establishes the head-discharge relationship.

Many nomographs and graphs have been developed for standard size pipe and box culverts. The staff of the Dam and Reservoir Safety Program uses Hydraulic Engineering Circular No. 10 published by the U.S. Department of Transportation (1972) to rate most culverts. Another good reference is Hydraulic Engineering Circular No. 5 published by the U.S. Department of Transportation (1965). Nomographs for determining flow in circular pipes are also included in the appendix of Design of Small Dams.

4. Flow under Bridges

In most cases, flow under bridges should be determined by performing a backwater analysis of the channel over which the bridge is located. However, in some cases, a single span bridge will pass flow as an orifice under low heads.

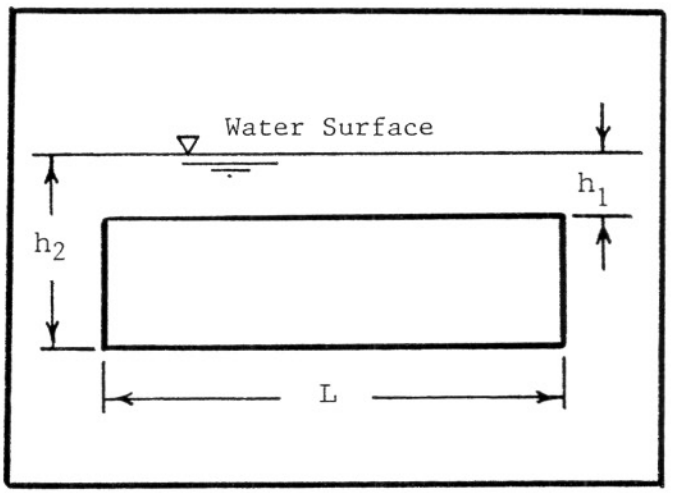


Figure 4.4 Flow Through a Rectangular Orifice

When the head on a vertical orifice is small in comparison with the height of the orifice, there is an appreciable difference between the theoretical discharge and the discharge given by Equation 4.5. Figure 4.4 shows a rectangular orifice of width L and height H. The respective heads on the upper and lower edges of the orifice are h_1 and h_2. Equation 4.7 gives the theoretical discharge for rectangular orifices.

$$Q_t = \frac{2}{3} L\sqrt{2g}(h_2^{1.5} - h_1^{1.5}) \qquad (4.7)$$

When Equation 4.5 is employed for orifices discharging under low heads, the deviation from the theoretical form of the formula must be corrected in the contraction coefficient. Equation 4.7 provides a better means of deriving the rating curve and does not require the estimation of a contraction coefficient.

B. Open Channel Hydraulics

Most dams have open channel principal spillways or emergency spillways which carry the majority of the flow during the design flood. It is important to know how to analyze the capacity of an open channel to determine if a dam will be overtopped. Many open channels have gentle slopes to prevent excessive erosion, but gentle slopes can cause backwater conditions in the channel. Depending on the flow rate, the control can move up or down the channel. Therefore, backwater analyses have to be be performed at several flow rates to determine the capacity of the channel.

TABLE 4.1

Geometric Elements of Trapezoidal Channels

Geometric Element	Symbol	Definition	Equation
Water Area	A	Cross sectional area of the flow normal to the direction of flow	$(b + zy)y$
Wetted Perimeter	P	Length of the line of intersection of the channel wetted surface with a cross sectional plane normal to the direction of flow.	$b + 2y\sqrt{1 + z^2}$
Hydraulic Radius	R	Ratio of the water area to its wetted perimeter.	$\frac{(b+zy)y}{b+2y\sqrt{1+z^2}}$
Top Width	T	Width of the channel section at the free surface.	$b + 2zy$
Hydraulic Depth	D	Ratio of the water area to the top width.	$\frac{(b+zy)y}{b+2zy}$
Section Factor	Z	Product of the water area and the square root of the hydraulic depth.	$\frac{[(b+zy)y]^{1.5}}{\sqrt{b+2zy}}$

Note y = depth of flow in channel

b = channel base width.

z = sideslope of channel, z:1.

An open channel is a conduit in which the flow has a free surface at all times. This contrasts with closed conduit or pipe flow in which the flow is completely enclosed. The free surface is subject to local atmospheric pressure, thus, the hydraulic grade line of a channel coincides with the water surface. This also has the effect of determining the location of the energy grade line since it is one velocity head $V^2/2g$ above the hydraulic grade line. The driving force which causes water to flow in open channels is the action of gravity along the slope of the channel.

Open channel flow may be classified and described in several ways. One such classification uses time as the criterion. Flow is considered to be steady if a parameter such as velocity or depth of flow at a point does not change over some time interval. The flow is unsteady if there is a change with respect to time.

Table 4.1 illustrates some of the common concepts used in open channel hydraulics. Channel sections are taken perpendicular to the direction of flow. The depth of flow, y, is the vertical distance from the lowest point of a channel section to the free surface. The water area, A, is the cross-sectional area of the flow normal to the direction of flow. The top width, T, is the width of the channel section at the surface. The wetted perimeter, P, is the length of the boundary in contact with the bottom and sides of the channel. The hydraulic radius, R, is the area divided by the wetted perimeter. The hydraulic depth, D, is the area divided by the top width, and is the characterictic length in open channels. Equations for these parameters are listed in Chow (1959) for various channel cross sections.

If space is used as the criterion, the flow is uniform if there is no change in velocity or depth along the length of a reach of channel. If a change does occur the flow is varied. Varied flow may be described as gradually or rapidly varied flow. In gradually varied flow, the rate of change of depth and velocity with respect to distance is relatively small so that some of the assumptions of uniform flow can be used for hydraulic calculations. Flow profiles caused by the backwater effect of a reservoir and changes in channel slope are examples of gradually varied flow.

A channel is prismatic if it has constant cross-section and slope over a reach; otherwise it is nonprismatic.

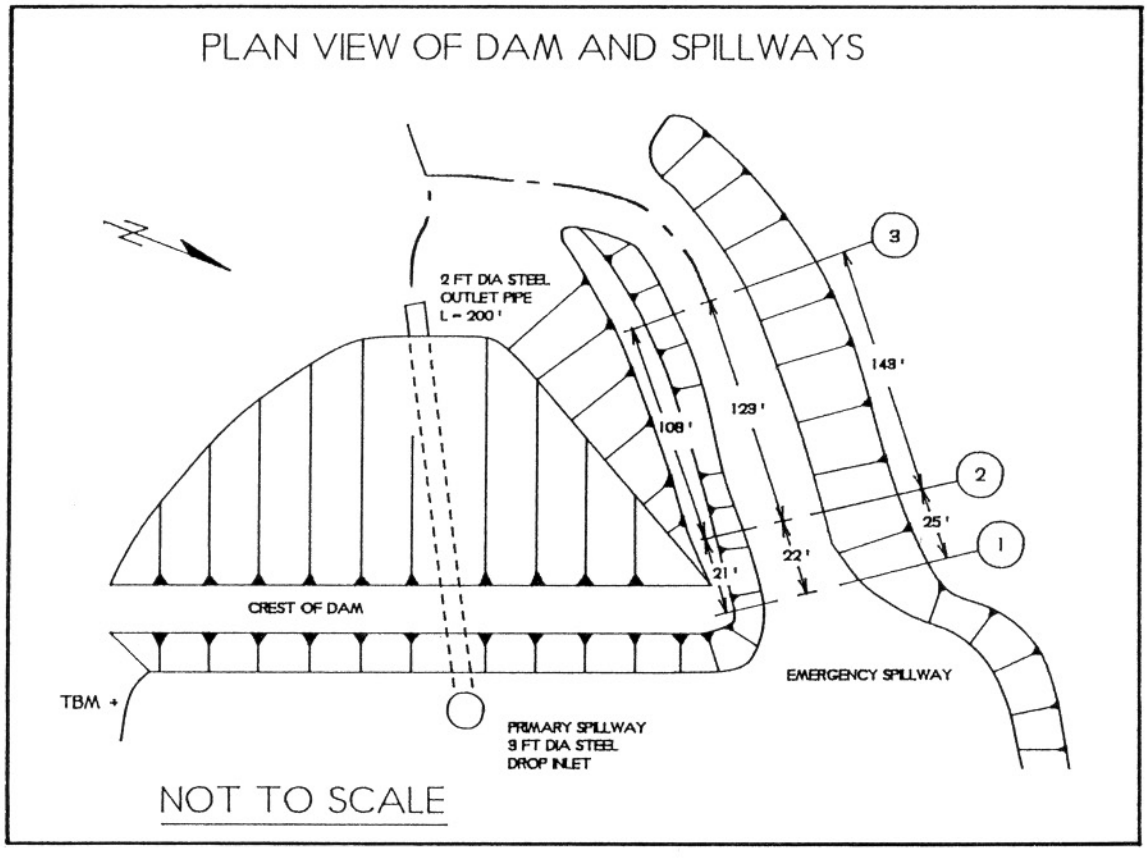


Figure 4.5 Plan View of an Earth Dam and Spillways

1. Water Surface Profiles

When water surface profiles are determined in an open channel spillway, the reservoir surface is assumed to be the elevation of the energy grade line at the upstream most cross section. In surveying an open channel spillway, the engineer should obtain cross sections at several locations both upstream and downstream of the assumed control section. This will ensure that sufficient information will be available to determine the approximate location of the control section. The results of a backwater analysis also allow the engineer to determine if the velocities in the channel are too high and if the training berm is high enough to prevent water from flowing outside the channel. Figure 4.5 shows a typical series of cross sections needed to perform backwater computations.

There are many methods available to compute water surface profiles in an open channel. The staff of the Dam and Reservoir Safety Program utilizes the U.S. Army Corps of Engineers (1982) HEC-2 Water Surface Profiles computer program to perform these calculations. The program calculates water surface profiles for steady gradually varied flow in natural or man-made channels. Both subcritical and supercritical flow profiles can be computed. The effects of various obstructions such as bridges, culverts, weirs, and structures in the channel may be considered in the computations. The computational procedure is based on the solution of the one-dimensional energy equation with energy loss due to friction evaluated with Manning's equation. The computational precedure is generally known as the Standard Step Method.

Figure 4.6 illustrates a short channel reach of length Δx which will be used to explain the basis of the standard step method. Equating the total heads at the two end sections 1 and 2, Equation 4.8 is produced:

$$S_o \Delta x + y_1 + \alpha_1 \frac{V_1^2}{2g} = y_2 + \alpha_2 \frac{V_2^2}{2g} + S_f \Delta x, \qquad (4.8)$$

where

S_O = slope of the channel bottom;
Δx = increment of channel reach;
y = depth of flow;
V = velocity of flow;
g = acceleration of gravity, 32.2 fps^2;
α = energy coefficient; and
S_f = energy gradient.

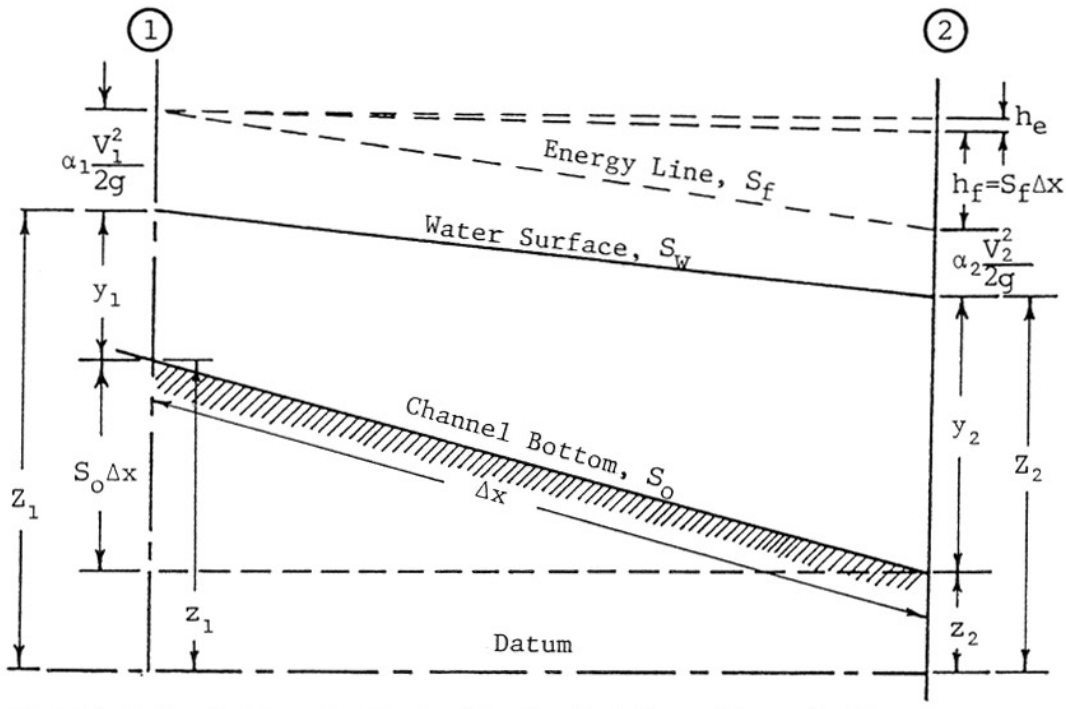


Figure 4.6 Energy in Gradually Varied Open Channel Flow

The water surface elevations at the two end sections are referenced to a horizontal datum as

$$Z_1 = S_o \Delta x + y_1 + z_2 \tag{4.9}$$

and

$$Z_2 = y_2 + z_2 \tag{4.10}$$

The friction loss is

$$h_f = S_f \Delta x = \frac{1}{2}(S_{f1} + S_{f2})\Delta x. \tag{4.11}$$

For ease of computation, the friction slope, S_f, is taken as the average of the slopes at the two end sections, or $\overline{S}_f$. Substituting Equations 4.9, 4.10, and 4.11 into Equation 4.8 yields

$$Z_1 + \alpha_1 \frac{V_1^2}{2g} = Z_2 + \alpha_2 \frac{V_2^2}{2g} + h_f + h_e, \tag{4.12}$$

where

α = energy coefficient; and
h_e = eddy losses.

The eddy loss depends mainly on the velocity head change and may be expressed as a part of it, or $k\left(\Delta\alpha \frac{V^2}{2g}\right)$ where k is a coefficient. For gradually converging and diverging reaches, k = 0 to 0.1 and 0 to 0.2, respectively. For abrupt expansions and contractions, k is about 0.5.

The total heads at the two end sections are

$$H_1 = Z_1 + \alpha_1 \frac{V_1^2}{2g} \tag{4.13}$$

$$H_2 = Z_2 + \alpha_2 \frac{V_2^2}{2g} \tag{4.14}$$

Substituting into Equation 4.12 yields

$$H_1 = H_2 + h_f + h_e \tag{4.15}$$

Equation 4.15 is the basic equation which is used to develop the procedure used in the standard step method. The standard step computation can be arranged in tabular form and solved as shown in Table 4.2.

The backwater computations must always be carried upstream if the flow is subcritical and downstream if it is supercritical. In computing a flow profile, the following information is generally required:

- The discharge for which the flow profile is desired.
- The water surface elevation at the control section. If this is not available, the comutation may start from an

TABLE 4.2

Standard Step Method of Computation

Station (1)	Z (2)	y (3)	A (4)	V (5)	$\alpha \frac{V^2}{2g}$ (6)	H (7)	R (8)	$R^{\frac{4}{3}}$ (9)	S_f (10)	$\overline{S}_f$ (11)	Δx (12)	h_f (13)	h_e (14)	H (15)

Before the computations begin, the flow rate must be specified as well as the channel roughness, n; slope, S_O; and energy coefficient, α.

Col. 1: Identify channel cross section by station number

Col. 2: Water surface elevation at the station. A trial value is first entered in this column; this will be verified or rejected on the basis of the computations made in the remaining columns of the table. For the first step, this elevation must be given or assumed. When the trial value in the second step has been verified, it becomes the basis for the verification of the trial value in the next step, and so on.

Col. 3: Depth of flow in feet, corresponding to the water surface elevation in column 2.

Col. 4: Water area corresponding to y in column 3.

Col. 5: Mean velocity equal to the given discharge, Q, divided by the water area in column 4.

Col. 6: Velocity head in feet, corresponding to the velocity in column 5.

Col. 7: Total head computed by Equation 4.13, equal to the sum of Z in column 2 and the velocity head in column 6.

Col. 8: Hydraulic radius in feet, corresponding to y in column 3.

Col. 9: Four-thirds power of the hydraulic radius.

Col. 10: Friction slope computed by $S_f = \frac{n^2 V^2}{2.22 R^{4/3}}$, with V from column 5 and $R^{4/3}$ from column 9.

Col. 11: Average friction slope through the reach between the sections in each step, approximately equal to the arithmetic mean of the friction slope just computed in column 10 and that of the previous step.

Col. 12: Length of the reach between the sections, equal to the difference in station numbers between the stations.

Col. 13: Friction loss in the reach, equal to the product of the values in columns 11 and 12.

Col. 14: Eddy loss in the reach, equal to zero.

Col. 15: Elevation of the total head in feet. This is computed by Equation 4.15, that is, by adding the values of h_f and h_e in columns 13 and 14 to the elevation at the lower end of the reach, which is found in column 15 of the previous reach. If the value so obtained does not agree closely with that entered in column 7, a new trial value of the water-surface elevation is assumed, and so on, until agreement is obtained. The value that leads to agreement is the correct water-surface elevation. The computation may then proceed to the next step.

assumed elevation at a section far enough away from the initial section through which the profile is desired.

- The geometric elements at various channel sections along the reach for all depths of flow within the range expected. Cross sections and reach length between are the two primary elements.

- The channel roughness and losses at each section.

Chow (1959) and Henderson (1966) provide an excellent discussion of the standard step method and procedures to compute backwater profiles.

One of the most difficult assessments that an engineer must make in the performance of a backwater analysis is the estimation of the surface roughness of the channel. Manning's n is a measure of surface roughness and is largely dependent on the material of which the channel boundaries are composed. There are several other factors which affect the value of n, including vegetation, channel irregularity, alignment, silting, scouring, obstructions, size and shape of channel, and depth of flow. Values of n are usually selected from tables for various materials or from pictures of channel for which values of n have been determined empirically. Chow (1959) and the United States Geological Survey (1967) are excellent references which should be used in estimating channel roughness. The following table can be used to estimate roughnesses for channels and closed conduits.

SURFACE	Min. n	Max. n
PVC Pipe	.010	.012
Concrete Pipe	.012	.015
Cast Iron Pipe	.013	.017
Grass Lined Channels	.020	.040
Rock Cut Channels, Smooth	.025	.040
Rock Cut Channels, Irreg.	.030	.045
Natural Streams	.025	.150

Vegetated open channel spillways usually consist of an inlet channel, a control section, and an exit channel. Subcritical flow occurs in the inlet channel and the flow is usually supercritical in the exit channel. Vegetated open channel spillways are typically trapezoidal in cross-section and are protected from erosion by a grass cover. While erosion damage is normally considered to be a maintenance related deficiency, it becomes a safety problem in cases where failure of the discharge channel will cause the flow to impinge on the toe or slopes of the embankment. As a general guideline, channels can be expected to suffer erosion damage when velocities exceed 8 fps.

The amount of erosion that will occur in a channel depends upon the characteristics of the soil, the type and density of the vegetation cover, the discharge velocity, and the duration and frequency of use. To minimize erosion, vegetated open channel spillways should be designed with horizontal or adverse sloped inlet channels and control sections that are located away from the dam. The anticipated average use of a vegetated open channel spillway should be kept to a minimum; it is preferable that the spillway be designed to carry flows only in excess of the 100-year event. In highly erodible soils, concrete sills or weirs should be constructed to stop headward erosion and prevent failure of the spillway.

All spillway flows should be confined to the channel with training berms or levees. Training berms must be high enough to contain the peak flow during the spillway design flood.

2. Critical Flow Computations

When an ogee spillway or a weir is located adjacent to the reservoir, the spillway rating curve can be determined by analyzing critical flow in an open channel. Critical flow is defined as the state of flow at which the specific energy, $y + \frac{V^2}{2g}$, is a minimum for a given discharge, Q. Using Equation 4.16, discharge rates can be computed at various values of critical depth.

$$Q = \sqrt{\frac{A^3 g}{T}}, \qquad (4.16)$$

where

Q = flow rate in cfs;
A = area of flow at critical depth in ft^2;
g = acceleration of gravity, 32.2 ft/sec^2; and
T = top width of water surface.

In order to develop a spillway rating curve, the reservoir elevation, $ELEV_{res}$, must be computed at each value of critical depth, y_c. This can be accomplished using Equation 4.17:

$$ELEV_{res} = ELEV_{sp} + y_c + \frac{V_c^2}{2g}, \qquad (4.17)$$

where

$ELEV_{res}$ = Elevation of the reservoir;
$ELEV_{sp}$ = Spillway crest elevation;
y_c = critical depth in feet; and
$\frac{V_c^2}{2g}$ = velocity head.

The only unknown parameter in Equation 4.17 is the velocity head, $\frac{V_c^2}{2g}$. It can be determined by using the continuity equation to compute the velocity at each value of critical depth, $V_c = \frac{Q}{A}$

Equation 4.16 should only be used to rate control structures such as weirs that will not become submerged by downstream conditions. It is always advisable to perform a backwater analyses of the discharge channel when there are questions about the channel's capacity and erosion resistance, or if training berms must be evaluated.

C. Reservoir Routing

Reservoirs can be routed by any number of level pool techniques. The basic requirements include reservoir elevation-storage information and a spillway rating curve. The beginning reservoir elevation should be the water storage elevation (normal pool) as defined by 10 CSR 22-1.020(62).

After the inflow hydrograph has been computed, the storm hydrograph must be routed through the reservoir. The staff of the Dam and Reservoir Safety Program uses the modified Puls routing method described by Chow (1964). This method assumes an invariable discharge-storage relationship and neglects the variable slope occurring during the passage of a flood wave. It is a satisfactory method for reservoir routing but should not be used for channel routing when unsteady flow conditions exist.

Modified Puls routing requires the solution of the continuity equation which can be expressed as

$$I - O = \frac{\Delta S}{\Delta t}, \qquad (4.18)$$

where

I = inflow into the reservoir;
O = outflow from the reservoir; and
S = water stored in the reservoir.

Equation 4.18 is exact but its application to practical problems involves approximations. The basic assumptions are that the water surface in the reservoir is level at all times and that the average of the inflow and outflow at the beginning and ending of a routing period are equal to the average flow during the period. Using subscripts 1 and 2 to denote the beginning and ending of a routing period gives

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_2 - S_1}{\Delta t} \qquad (4.19)$$

Arranging Equation 4.19 so that all known values are on the left yields

$$\frac{I_1 + I_2}{2}\Delta t + S_1 - \frac{O_1 \Delta t}{2} = S_2 + \frac{O_2 \Delta t}{2} \qquad (4.20)$$

The assumption that $(I_1 + I_2) / 2$ equals the average inflow during a routing period implies that the inflow hydrograph varies linearly over the time step, Δt. Thus the controlling factor in selecting the routing period Δt is that it be sufficiently short so that this assumption is not seriously violated. The routing period should never be greater than the time of travel through the reservoir and should be chosen to ensure that the peak of the inflow hydrograph will be considered. As a rule of thumb, the routing period should be long enough to consider at least four inflows on the rising limb of the inflow hydrograph.

The two relationships that must be developed to solve Equation 4.20 involve the outflow from the reservoir and storage within the reservoir. This section will consider only storage in the reservoir. The previous sections in this chapter addressed the issue of outflow, which is determined by rating both closed conduit and open channel spillways.

Like basin area, reservoir areas can be determined from a topographic map using a planimeter. The reservoir's water surface area should be determined at each successive contour from the toe to the top of the dam. For dams that have been in existence several years, contour lines may not extend below the normal pool elevation. In this case, only reservoir volumes above normal pool can be computed. Hydrographic surveys are useful to determine the amount of silt in the reservoir but they are not required to perform reservoir routing.

The volume between successive contours can be determined by either of two methods: the average end area method or the conic method. The average end area method averages the area between two successive contours and multiplies the result times the change in elevation as shown in Equation 4.21

$$\Delta Vol = \left(\frac{A_n + A_{n+1}}{2}\right)(E_{n+1} - E_n), \qquad (4.21)$$

where

ΔVol = volume of storage between elevations E_n and E_{n+1};
A_n = water surface area at elevation E_n;
A_{n+1} = water surface area at elevation E_{n+1}; and
E = elevation.

The conic method can be used to compute reservoir volume from surface area versus elevation data as follows:

$$\Delta Vol = (E_{n+1} - E_n)(A_n + A_{n+1} + \sqrt{A_n A_{n+1}})$$

After the reservoir volumes have been computed, a graph of elevation versus storage is developed. Using this graph and the spillway rating curve, a graph of discharge versus storage is created as shown in Figure 4.7. Each point on the curve represents reservoir storage and outflow at a given elevation. Figure 4.8 is a plot of outflow, O, versus $\left(S + \frac{1}{2}O\Delta t\right)$. This graph is obtained by adding to the abscissa of the storage curve, Figure 4.7, one half of the value of $(O\Delta t)$. At the beginning of a routing period, the known values are the inflows for periods 1 and 2 and the outflow at period 1. The goal is to determine the outflow for period 2.

The modified Puls routing procedure involves the following steps:

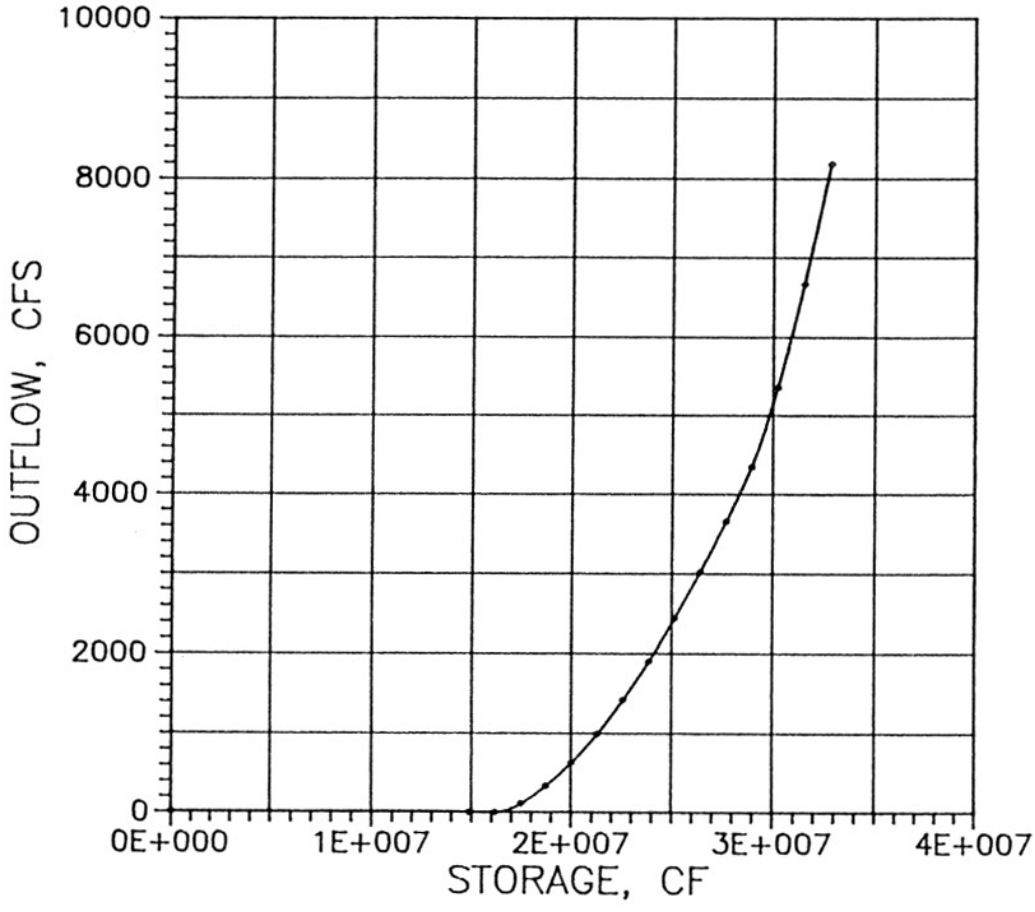


Figure 4.7 Storage Versus Outflow Curve for a Reservoir

Step 1 Compute $(I_1 + I_2)/2$, the average inflow.

Step 2 For an initial outflow, O_1, the storage S_1 is obtained from the storage versus outflow curve, Figure 4.7.

Step 3 Compute the quantity $\left(S_1 - \frac{1}{2}O_1\Delta t\right)$.

Step 4 Using Equation 4.18, determine the quantity $\left(S_2 + \frac{1}{2}O_2\Delta t\right)$ by adding the average inflow plus the quantity $\left(S_1 + \frac{1}{2}O_1\Delta t\right)$.

Step 5 Determine the outflow O_2 corresponding to $\left(S_2 + \frac{1}{2}O_2\Delta t\right)$ from Figure 4.8.

Several iterations of these computations are performed to construct the outflow hydrograph which is a plot of time versus outflow, O_2. The maximum water surface elevation during the design flood is then determined from the peak rate of outflow.

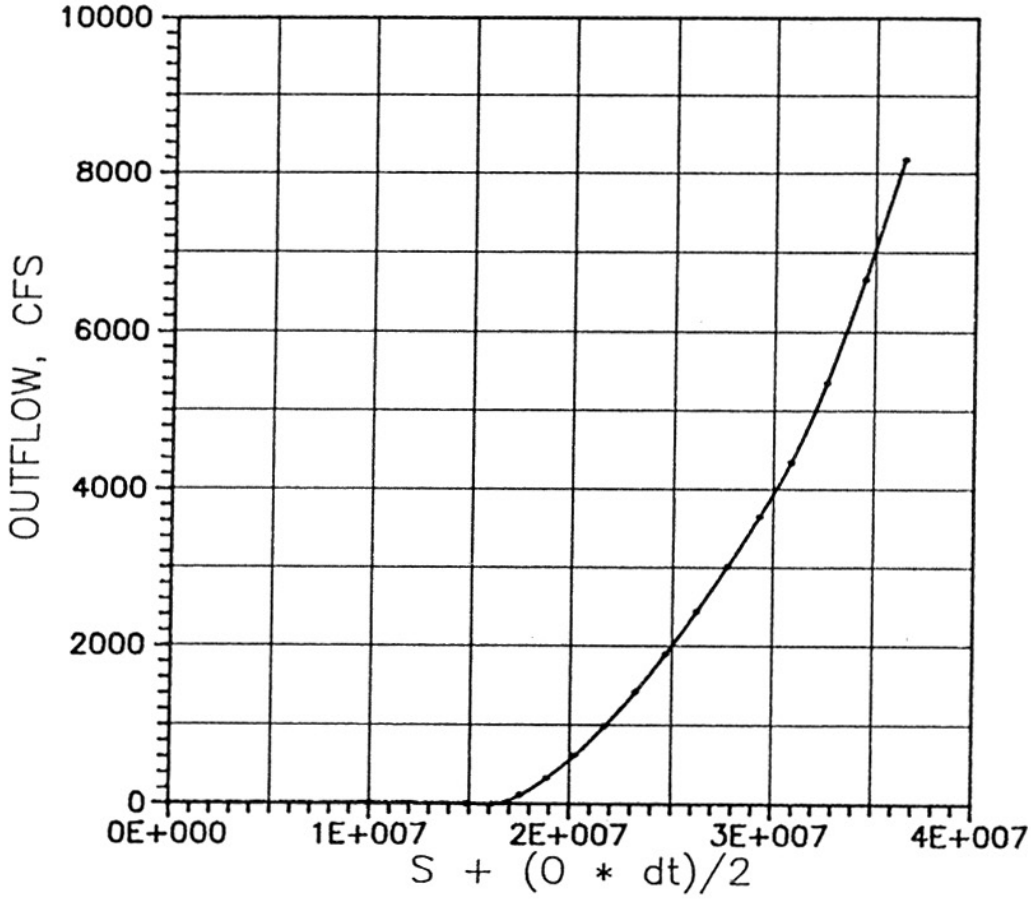


Figure 4.8 S + (O · dt)/2 Versus Outflow Curve for A Reservoir

CHAPTER V

GEOTECHNICAL CONSIDERATIONS

The geotechnical considerations in this chapter will focus on earth, rockfill and tailings dams. Figure 5.1 illustrates the differences between the three types of dams.

Rolled earthfill dams are constructed in successive mechanically compacted layers. They can be constructed as homogeneous embankments or as zoned dams with an impervious core. Homogeneous dams are constructed entirely or almost entirely of a single embankment material. They are so named to distinguish them from zoned dams, which contain different materials in different parts of the embankment. The downstream slope of a homogeneous dam on an impervious foundation will theoretically develop seepage to a height of roughly one-third the depth of the reservoir pool. Sometimes, homogeneous and zoned embankments are constructed with internal drains to control seepage. Chimney, blanket and trench drains are three of the more common types of internal drains used in Missouri. Internal drains serve two important purposes. They control seepage and reduce the pore pressure in the downstream portion of the dam thereby improving the stability of the dam.

Rockfill dams usually have an impervious core which is flanked by zones of material considerably more pervious. The pervious zones enclose, support, and protect the impervious core; the upstream pervious zone affords stability against rapid drawdown; and the downstream pervious zone acts as a drain to control the line of seepage. To prevent internal erosion of the impervious core, a filter is placed between the core and the downstream rock shell.

Tailings or industrial water retention dams are used by mining companies to store waste rock from mining. All tailings dams greater than 35 feet in height are regulated under the dam safety law. The three types of tailings dams currently in existence in Missouri are lead, barite, and iron tailings. Each of these dams typically includes a clay starter dam which is normally constructed as a homogeneous earthfill embankment.

Lead tailings used in dam construction are typically ground limestone and dolomite. The silty sand tailings have a gradation ranging from a #40 to a #200 sieve. On-dam cycloning (Vick, 1983) is the primary method used to disposit lead tailings in Missouri. Underflow sand from each hydro-cyclone is discharged toward the embankment face, and overflow slimes are discharged into the impoundment. A wide zone of slimes adjacent to the upstream slope of the dam helps restrict the flow of seepage through the dam.

Barite tailings used in dam construction consist of well graded gravel. Barite slimes have low permeability and consist of red and dark brown clay.

Iron tailings dams are built with crushed rock that ranges in size from 1/4 to 5/8 inch. In order for iron tailings dams to retain water, a clay blanket or an impermeable liner must be placed on the upstream slope.

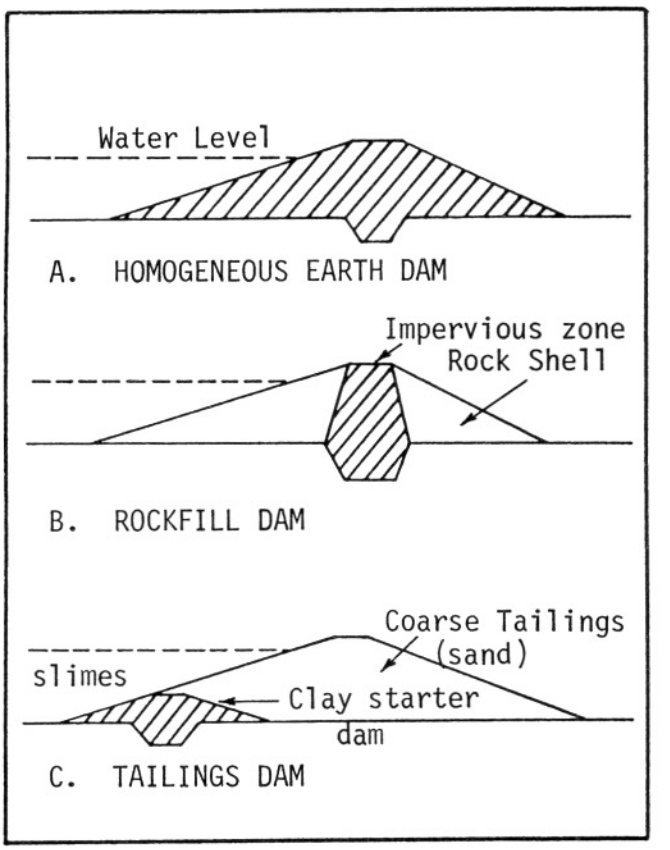


Figure 5.1 Types of Dams in Missouri

Tailings dams can be constructed by the upstream, centerline and downstream methods as shown in Figure 5.2.

The geotechnical analysis of industrial water retention dams involve seepage, slope stability and seismic response computations. The design for all new dams built in Missouri after August 13, 1981 must include a geotechnical analysis to show that the dam will meet the criteria in 10 CSR 22-3.020. A geotechnical analysis is not required for dams that were in existence prior to August 13, 1981 unless the height, slope or reservoir elevation is being modified.

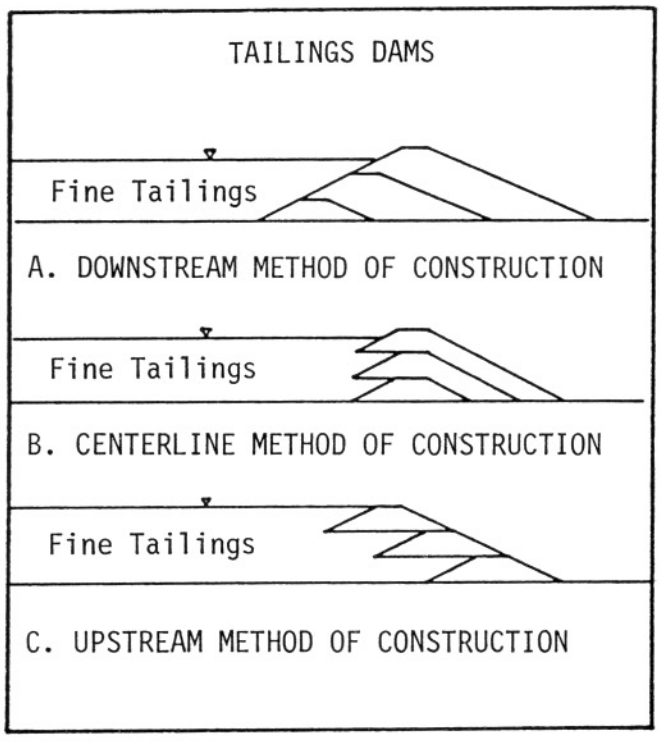


Figure 5.2 Methods of Constructing Tailings Dams

A. Soil Classification

Knowledge of soil classification, including typical engineering properties of soil groups, is essential when investigating earth materials or foundations for structures. Soil classification can be used to estimate engineering characteristics of soils for use in the analysis of small dams.

The Unified Soil Classification System is recommended for use in the classification of soils. Figure 5.3, the Unified Soil Classification Chart, is the basis for soil classification under this system.

In addition to proper classification, it is important to include an adequate description of the soil in reports or logs of explorations. The classification chart contains the information required for describing soils, citing several examples.

B. Foundation Cutoffs

Many dam sites have a foundation consisting of alluvial deposits of permeable sand and gravel, silt, or weathered rock at or near the surface with an impervious (less permeable) stratum of rock, clay, or shale at a greater depth. For these sites, a positive cutoff is recommended to assure a successful and stable dam. The cutoff should intersect the impervious stratum and be an extension of the core of the embankment. A positive cutoff is particularly important where the water in storage is used for irrigation or water supply.

Where a positive cutoff is impractical because of the depth to an impervious stratum, a partial cutoff may provide foundation stability and reduce seepage losses to acceptable levels. Regardless of the foundation conditions, the only way to determine the economical feasibility of a positive cutoff or partial cutoff is to make a seepage analysis and water balance.

C. Foundation and Embankment Drainage

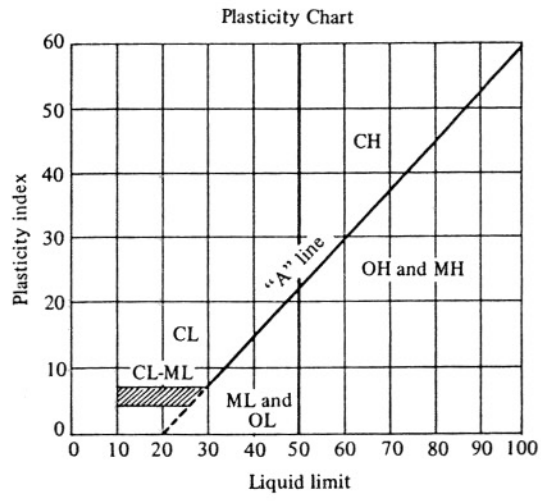
The impervious portion of an earthfill dam provides resistance to seepage, which creates the reservoir. Soils vary in permeability, and even the tightest clays can transmit seepage. Therefore, seepage control is a major concern in dam design. Filter and drainage systems must have adequate capacity but still control the movement of fine grained soil particles through the embankment. Internal erosion of fine grained soil can lead to a condition known as "piping" in which a conduit or pipe forms within the embankment. If allowed to continue, the erosion can eventually migrate upstream to the reservoir and cause a total failure of the dam.

The movement of reservoir water through the dam depends on the reservoir level, the degree of permeability of the embankment material in the horizontal and vertical directions, the amount of remaining pore-water pressures caused by compressive forces during construction, and the distance over which the seepage travels. The upper surface of seepage is called the phreatic surface; in a cross section, it is referred to as a phreatic line. Although the soil may be saturated by capillarity above this line, giving rise to a "line of saturation," seepage is limited to the portion below the phreatic line.

Drains are included in embankments and foundations for two basic reasons: to prevent piping by controlling migration of soil particles under seepage flow; and to control pressure build-up by allowing free drainage of seepage flow. There are no hard and fast rules for selecting a margin of safety for the capacity of internal drains. Cedergren (1977), recommends that drains be designed to carry at least ten times as much seepage as expected due to difficulty in estimating permeability of the drain material and seepage rates. Judgement is required and should be related to past experience with similar materials and an evaluation of the data obtained during the site investigation and testing program.

In recent years, many engineers have opted to use geotextiles as filters for granular drains. Geotextiles can be either woven or nonwoven. They are used in subsurface drainage systems as a permeable separator to keep soil

Major Divisions			Group Symbols	Typical Names	Laboratory Classification Criteria		
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 per cent GW, GP, SW, SP; More than 12 per cent GM, GC, SM, SC; 5 to 12 per cent *Borderline* cases requiring dual symbols[b]	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM[a] d u	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures		Atterberg limits below "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP	Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM[a] d u	Silty sands, sand-silt mixtures		Atterberg limits above "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures		Atterberg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity			
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH	Inorganic clays of high plasticity, fat clays			
			OH	Organic clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt	Peat and other highly organic soils			



[a]Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterberg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.
[b]Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

Figure 5.3 Unified Soil Classification Chart (ASTM D-2487)

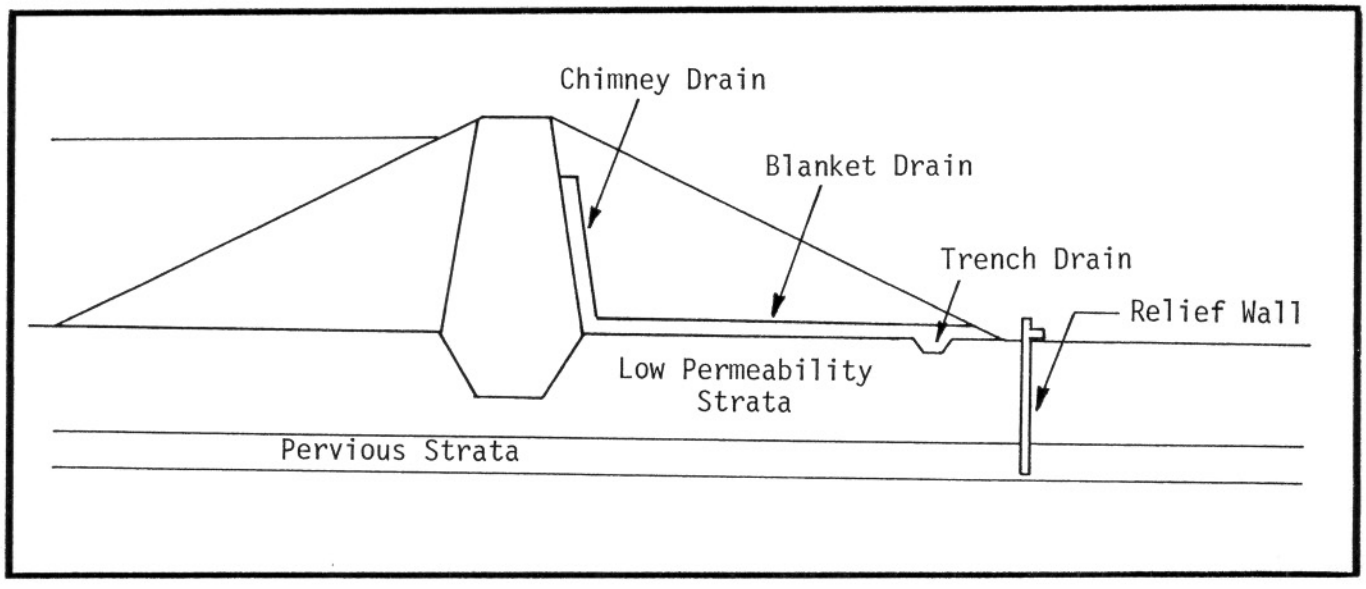


Figure 5.4 Types of Drains

out of the drainage media and permit water to pass freely. Permittivity (capacity to pass water) and pore size (opening size) are critical characteristics of geotextiles. Nonwoven geotextiles are frequently used in dam construction because of their high flow capacity and small pore size. Care should always be taken to assure an effective installation.

Four types of drains will be discussed: chimney drains, blanket drains, trench drains and relief wells. These are shown in Figure 5.4. It should be noted that the selection of the drainage media is a very important consideration. Crushed limestone should not be used. Instead, river run gravel or sand (quartz and chert material) should be selected to ensure the long term success of the drain.

1. Chimney Drains

Chimney drains are primarily interceptors that provide positive control of embankment seepage. With a chimney drain, water that percolates through the soil is intercepted to prevent seepage in the materials downstream from the drain. Chimney drains are applicable where the downstream embankment material cannot be allowed to become saturated and where the horizontal permeability of the fill is significantly higher than the vertical permeability. It may be more economical to place poor materials in a "random fill" zone downstream from a chimney drain than to waste them. Chimney drains are also applicable where embankment materials are susceptible to cracking.

2. Blanket Drains

Horizontal blanket drains occasionally are used in new dams in Missouri. They are primarily used to intercept foundation seepage and prevent saturation of the dam. Horizontal blanket drains are applicable where there is no significant difference between the vertical and horizontal permeability of the embankment or the foundation; where bedrock is pervious (if the drain is placed directly on bedrock); or where a good bond cannot be obtained between bedrock and the embankment and underseepage is a problem.

3. Trench Drains

Trench drains are used more frequently then the other drain types in both new dams and modifications to existing dams. They can be used to provide drainage to the foundation, embankment or abutments. Trench drains are typically excavated with a back hoe and lined with geotextile filter fabric. River run gravel works well as a drainage medium.

Prefabricated drainage composites can also be used as a trench drain, especially in modifications to existing dams. They provide consistent in-place drainage and can reduce the material cost, installation time, and design complexity in some applications. Prefabricated drainage composites typically are two-component materials consisting of a three-dimensional drain core or net with a fabric attached. Water passes through the fabric and into the core. The core acts as a collector and transporter of seepage while the fabric acts as a filtering medium.

4. Relief Wells

Relief wells are generally located near the downstream toe of an embankment. They are particularly adapted for control of pressures from confined and alluvial aquifers

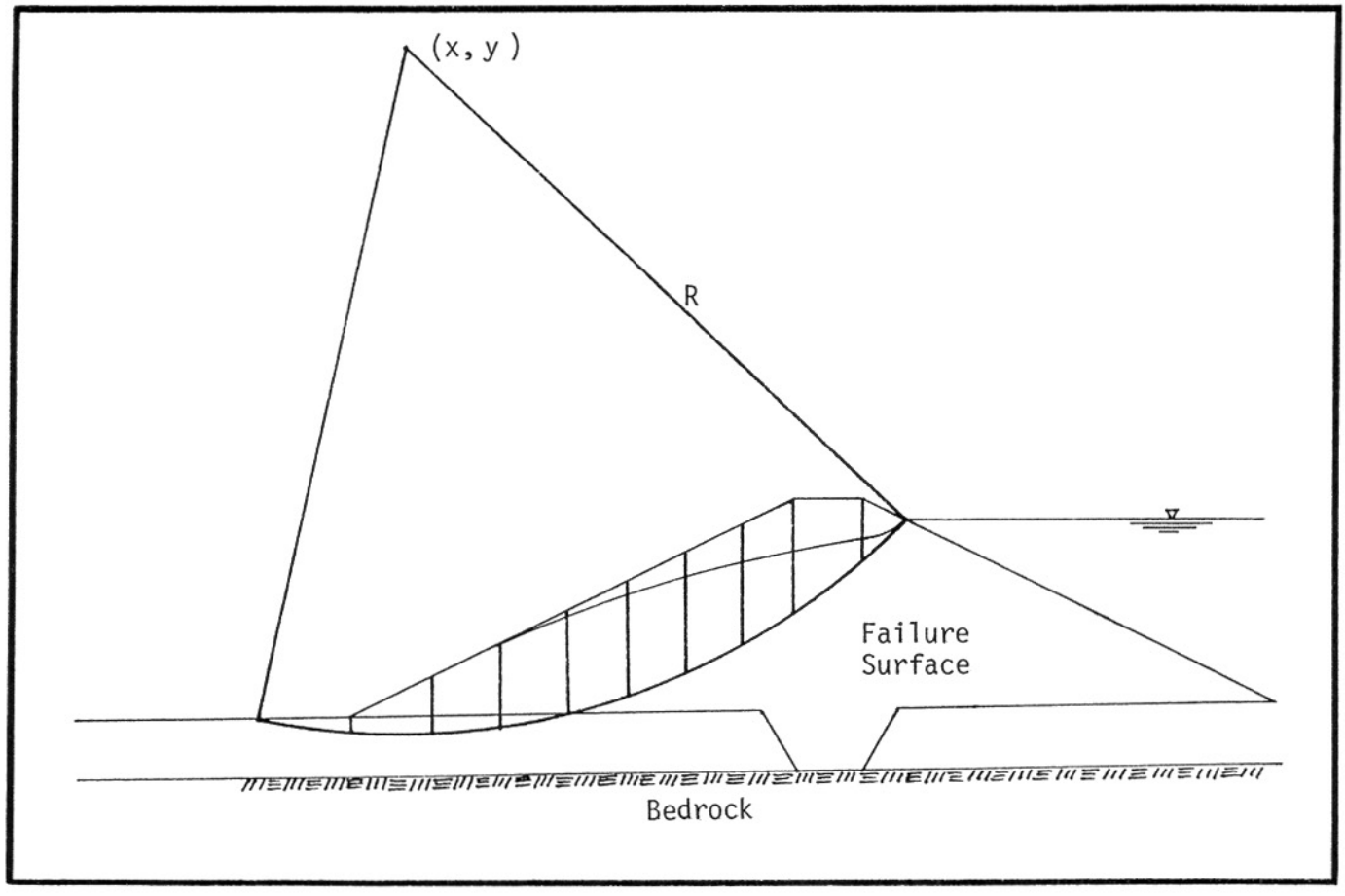


Figure 5.5 Circular Failure Surface in an Earthfill Dam

that are too deep to be drained with foundation drains. They are often used in conjunction with other types of drains.

Drain outlets are needed to conduct the accumulated seepage from all internal drains to a controlled discharge point. PVC pipe works well and provides the dam owner with a outlet location at which to measure the seepage rate.

Two excellent discussions on the subject of internal drains and filters were written by Sherard, Dunnigan, and Talbot (1984).

D. Structural Stability

The potential for failure from sliding, sloughing and rotation must be analyzed, documented and incorporated in the design of all new dams. Embankment and foundation design and geotechnical exploration should be consistent with the complexity of the site and the potential for failure. Anticipated settlement, seepage, and cracking should be considered and documented.

The slope stability criteria used in this manual is that contained in 10 CSR 22-3.020, Tables 1, 3, and 4. Various procedures are available for calculating the factors of safety of embankment sections. The basic methods include the circular arc and the sliding wedge methods.

The staff of the Dam and Reservoir Safety Program use the ICES LEASE and STABL computer programs to perform slope stability analyses. Both programs employ the simplified Bishop Method which divides potential failure surfaces into slices for analysis. Figure 5.5 depicts a circular failure surface in an embankment dam. The factor of safety is the ratio of the moment of shear strength (resisting forces) along the failure surface to the moment of the weight of the failure mass (driving forces). To determine the minimum factor of safety for a dam requires the analysis of several failure surfaces.

The simplified Bishop Method uses a basic moment equilibrium equation for the summation of forces on each

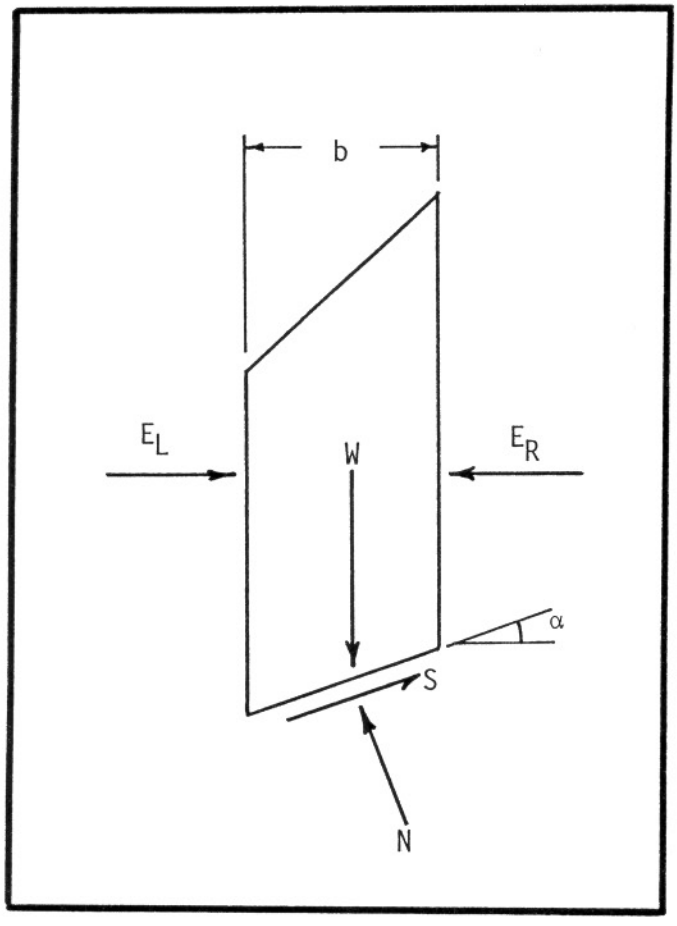


Figure 5.6 Free Body Diagram - Simplified Bishop Method

slice as shown in Figure 5.6. Symbols and definitions are given below.

W = total weight of slice, soil plus water;
b = width of slice;
E_L = Force acting on left boundary of slice;
E_R = Force acting on right boundary of slice;
S = resultant of friction and cohesion forces;
N = effective normal force;
α = angle between the base of each slice and horizontal.

The method sums the vertical components of the forces. The side forces are assumed to be equal, horizontal, and colinear. The factor of safety is computed by Equation 5.1:

$$F = \frac{\sum\left[c + \left(\frac{W}{b} - u\right)\tan\phi\right]b\left(\frac{1}{M_\alpha}\right)}{\sum(W\sin\alpha)}, \qquad (5.1)$$

where

c = cohesion of soil at the bottom of the slice;
W = total weight of slice, soil plus water;
b = width of slice;
u = hydrostatic pressure on the bottom of the slice;
ϕ = angle of frictional resistance of soil;
$M_\alpha = f(F) = \left[1 + \frac{\tan\alpha\tan\phi}{F}\right]\cos\alpha$; and
α = angle between the base of each slice and horizontal.

Except for M_α, all of the parameters in Equation 5.1 are based on the physical characteristics of the failure surface and the soil. Once these parameters are determined, Equation 5.1 can be solved iteratively. This is necessary because the factor of safety term, F, is on both sides of the equation.

A trial factor of safety value can be computed from Equation 5.2:

$$F_1 = \frac{\sum(cb + W\tan\phi)}{\sum(W\sin\alpha)} \qquad (5.2)$$

The parameter, F_1, is used to calculate M_α and solve Equation 5.1. The result of Equation 5.1 is used in the next iteration and the process is repeated until convergence occurs. Lambe and Whitman (1969), Perloff and Baron (1976), and Huang (1983) have provided a good description of the simplified Bishop procedure in detail.

Analyses are to be made for the loading conditions that are most critical during the design life of the structure. For new dams, the following conditions must be considered: (1) end of construction; (2) steady seepage - full reservoir; (3) steady seepage - maximum reservoir; (4) sudden drawdown; and (5) earthquake. When modifications are made to the slopes, height or water storage elevation of dams built before August 13, 1981, only the steady seepage and sudden drawdown cases must be analyzed.

Selection of the soil strength parameters is the most important facet of the slope stability analysis. Unlike steel and concrete, soil strengths vary widely, depending on the type and location of the soil. When testing a soil, the soil strength depends upon consolidation (effective confining) pressure, drainage during shear, volumetric history, disturbance, and strain rate. In most cases, the strength of a soil can be expressed by Equations 5.3 and 5.4:

$$\bar{\tau} = \bar{c} + (\sigma - u)\tan\bar{\phi}, \qquad (5.3)$$

where

$\bar{\tau}$ = effective shear stress on the surface at failure;
$\bar{c}$ = cohesion intercept based on effective stresses;
σ = total normal stress acting on the failure surface;
u = pore water pressure;
$\bar{\phi}$ = friction angle based on effective stresses;

and

$$\tau = c + \sigma \tan\phi, \qquad (5.4)$$

where

τ= shear stress on the surface at failure;

c= cohesion intercept;

σ= total normal stress acting on the failure surface; and

ϕ= friction angle.

As depicted in Equations 5.3 and 5.4, two basically different approaches to the stability problem can be used by the engineer: the effective stress method and the total stress method. Drained strength parameters are used in an effective stress analysis while undrained strength parameters are used in a total stress analysis. According to Sherard et. al. (1963), there are two advantages of the effective stress method: the analysis is carried out with a somewhat more fundamental definition of the shear strength; and pore pressures assumed in the design can later be compared with those which develop in the dam and foundation as measured by piezometers.

In preparation for performing the stability analysis, the engineer should develop a cross section of the dam at the maximum section. The cross section should show all soil zones and their respective properties. Internal drains should be clearly delineated. The phreatic surface must be estimated using analytical methods or piezometric data. The estimated phreatic surface should be depicted on the cross section.

1. End of Construction Case

In the end of construction case, both the upstream and downstream slopes of a dam must be examined for stability. The most conservative condition assumes that the compacted soil does not consolidate under the weight of the soil layers above it and is sheared before drainage can occur. In reality, some dissipation of pore pressures occurs, with an increase in strength of the soil. Estimation of such dissipation of pressure with gain in strength is inexact. A pore pressure instrumentation system may be installed to verify the dissipation of pressures; however this is generally not economically feasible for small to medium sized dams. Soil strength values for the instantaneous end of construction condition can be obtained from the unconsolidated-undrained (UU) triaxial test.

In analyzing the end of construction factor of safety for the downstream slope, the staff of the Dam and Reservoir Safety Program examines all failure surfaces that would result in the release of water from the reservoir. The upstream slope is analyzed by examining all failure surfaces that intercept the crest.

2. Steady Seepage Cases

The two steady seepage conditions that must be analyzed are characterized by the completion of two processes. First, the soil in the dam has been consolidated by the overlying soil and second, all pore pressures have dissipated to values determined by the position of the phreatic surface. These cases are normally critical for the downstream slope because the seepage forces act in the downstream direction and the reservoir supports the upstream slope.

To determine the shear strength parameters, a representative soil sample is compacted to the design density, consolidated under a representative overburden stress, and fully saturated. It is then sheared under fully drained conditions. An alternative is to use the results of a consolidated-undrained (CU) triaxial test with pore pressure measurements. With either method, drained strength parameters are determined. Pore pressures within the dam are estimated from a flow net or as a function of the depth below the phreatic surface. The phreatic surface for a homogeneous dam on an impervious foundation can be estimated as shown in Figure 5.7.

Following Casagrande's (1937) procedure, it is assumed that the theoretical line of seepage starts from the pool level at a distance of 0.3Δ from the dam, where Δ is the horizontal distance from the upstream toe to the point where the reservoir elevation meets the upstream slope of the dam. Utilizing an x,y coordinate system with the origin at the downstream toe, the exit point of the phreatic surface can be computed from the known values of h and d in Figure 5.7. As an approximation, the y coordinate of the exit point can be taken as 0.33h and the phreatic surface can be drawn as a smooth curve between the entrance and exit points. The phreatic surface is thus assumed to be a parabola tangent to the downstream slope.

Huang (1983) developed tables to compute the exit and mid points as a function of d and h for downstream slopes ranging from s = 1.5 to 5.0. Huang's method can be used in embankment sections on an impervious base and without internal drains. Other methods of approximating the shape of the phreatic surface must be used when internal drains are located in the dam. In most cases, the staff of the Dam and Reservoir Safety Program estimates the shape of the phreatic surface in Figure 5.7 as 2-3 chords which connect the entrance and exit points.

Piezometric data from an existing embankment can also be used to develop the phreatic surface for use in the stability analysis.

In analyzing the steady seepage cases, the staff of the Dam and Reservoir Safety Program examines all failure surfaces that would result in the release of water from the reservoir. The cross section of the dam at the maximum section is analyzed. For the steady seepage-maximum reservoir case, the phreatic surface is assumed to be in the same location as the steady seepage-full reservoir condition unless the dam has an upstream pervious zone.

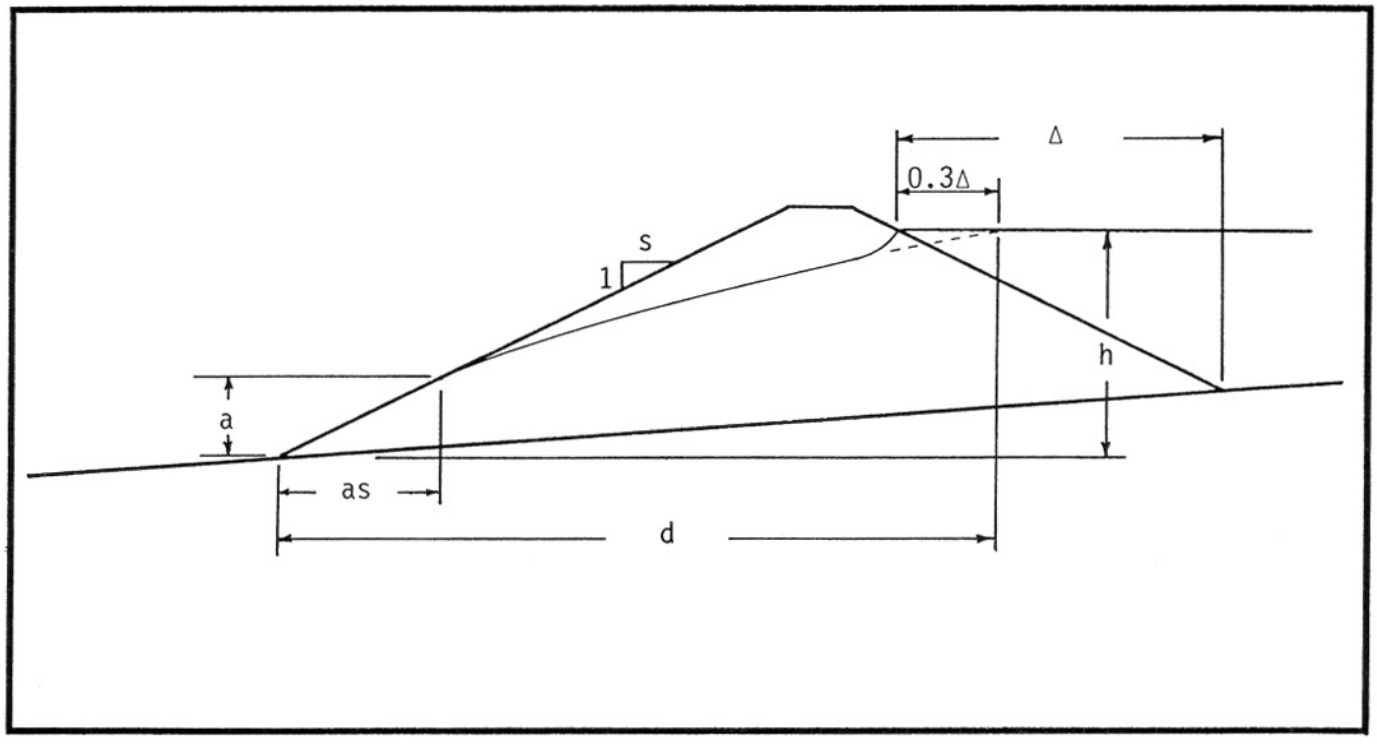


Figure 5.7 Phreatic Surface in an Earthfill Dam

3. Sudden Drawdown

The sudden, or rapid drawdown condition can be critical for the upstream slope of any dam where the reservoir elevation can be drawn down by a lake drain pipe or by other means. If the reservoir level cannot be drawn down quickly, this condition does not have to be analyzed.

In the sudden drawdown case, the soil is fully consolidated under the weight of the overlying material, and saturation with a static water level or a steady seepage condition is established. As the drawdown occurs, buoyancy forces are eliminated in the soil zone above the lowered reservoir elevation. The soil is sheared under undrained conditions by the increased weight of the saturated soil above the lowered reservoir elevation. The shear strength, however, is still governed by the consolidation that occurred before drawdown. The effective normal stress before drawdown should be used to calculate frictional resistance at the assumed failure surface.

The information and shear strength parameters required for the sudden drawdown analysis are obtained from the consolidated, undrained (CU) triaxial tests. The cross section of the dam at the maximum section should be used and the phreatic surface assumed to be in the same location as the steady seepage-full reservoir condition. The staff of the Dam and Reservoir Safety Program examines all failure surfaces that intercept the crest of the dam.

4. Earthquake

The required accelerations for earthquake design are listed in Table 4, 10 CSR 22-3.020. They are termed the Probable Maximum Acceleration and are dependent upon the location of the dam and the downstream hazard classification. These accelerations should be used with the cross section analyzed in the steady-seepage, full reservoir condition to determine the seismic stability of the embankment. The acceleration imparts a horizontal force to each slice which increases the moment of weight of the failing mass. As in the steady seepage cases, effective stress parameters should be used in the analysis.

Earthquake loading may result in the build-up of pore water pressures and a loss of strength for new dams constructed wholly or partially of cohesionless materials (such as sand and silt) or having a foundation of cohesionless materials. Engineers shall take this pore pressure increase and loss of strength into account when performing their stability analysis. The degree to which liquefaction may affect the factor of safety for slope stability is left up to the engineer's best judgement. Dynamic analyses of earth embankments are not required. Typically, a pseudo-static

analysis can be conducted to determine the likelihood of failure. In conductin g the analysis, very low strength parameters are assumed for the liquefaction zones.

E. Protection of Upstream Slopes

It is generally necessary to protect the upstream face of a dam from wave erosion. The orientation and length of the permanent pool, the purpose of the reservoir, and the duration of stages in flood control pools all affect the need for and the type of embankment protection. Embankments in northern Missouri that are constructed of friable, or loessial, soils are particularly susceptible to upstream slope erosion. Minor water level fluctuations lift soil particles from exposed surfaces and leave vertical banks along the water line.

Upstream slope protection usually consists of rock riprap, either dumped or handplaced. As a minimum, rock riprap should consist of hard durable rock, well graded, placed at a minimum thickness of 18 inches on 6 inches of well-graded gravel or a layer of geotextile (filter cloth). On dams with small reservoirs, a properly designed beaching slope can be used instead of riprap.

Judgement is required in the design of the vertical height of riprap. Protection should be provided both above and below the water storage elevation. The protection below the normal pool elevation is dependent upon several factors including the purpose of the reservoir and the base flow of the inflow stream. A water supply reservoir will generally have a wide range of stages during the year due to withdrawals. A recreation dam on a stream with a year round base flow normally only requires a minimal amount of riprap below the normal pool elevation. Maximum protection can be obtained by placing riprap on the upstream face of the dam from the toe to the crest; however, this is expensive and is normally not justified on smaller dams. As a general rule, riprap should be placed a few feet above and below the water storage elevation.

A recommended reference for the design of riprap slope protection is Riprap for Slope Protection Against Wave Action, (SCS, 1983).

F. Instrumentation

Instrumentation can significantly improve the overall safety of a dam by providing continuous surveillance of the structure. Instrumentation is normally associated with large high hazard dams, but it is also used in dams with unusual design features.

Instrumentation refers to the method and equipment used to make physical measurements of dams. Instrumentation is not, however, a substitute for inspection. It is a supplement to visual observations and inspections. Visual examinations are aided by monitoring instruments that measure seepage and leakage through and around the embankment, movements of the embankment and foundation, and water levels and pressures within the embankment and the foundation. Where instrumentation exists, adequate records of measurements, along with the visual observations, should be maintained. To be effective, these records should be continuous and periodically reviewed by a professional engineer experienced in the design and operation of embankment structures. Any change in behavior of the dam would signal a need for further review and analysis.

There are three general types of instruments used to monitor dams. These include seepage monitoring instruments, embankment movement instruments and water pressure instruments (piezometers). An excellent discussion of instrumentation is included in the Training Aids for Dam Safety (TADS) module entitled, Instrumentation for Embankment and Concrete Dams.

1. Seepage and Leakage

All dams seep to varying degrees and all seepage should be monitored and recorded. If there is visible flow, the quantity of water should be measured by channelizing the seepage and installing a pipe, weir, or a flume. A record should be kept of the discharge rate, the temperature of the seepage, and the reservoir elevation. Toe and/or foundation drains should also be monitored and data recorded along with the reservoir elevation. Any wet spots should be noted and the location, size, and condition recorded.

2. Embankment Movements

Considerable movement of embankment dams can be anticipated during and immediately after construction. Much of the movement may be attributed to foundation settlement under the load of the embankment. The embankment will also move as the reservoir is filled for the first time and may periodically experience cyclic movements as the reservoir is emptied and filled in succeeding seasons. Movements are determined by periodic measurements of monuments placed in or on the structure and abutments. For existing dams, monumentation to measure movements is usually limited to the crest and downstream slopes. The monuments are anchored in the embankment below the depth of normal seasonal volume change. Abutment monuments usually consist of steel rods or surveyor's markers embedded in concrete and placed in excavations in the abutments. Differences in elevation and location of the monuments are measured by transit and level surveys of the monuments.

Measurements of the locations of monuments on the surface of the embankment should be such that changes in both vertical and horizontal locations are measured. The measurements should be reduced to graphical displays of changes in vertical location, changes in horizontal

location along the axis of the embankment, and changes in horizontal location transverse to the axis of the embankment (upstream and downstream). The water surface elevation in the reservoir at the time of measurement of the monument is important and should be recorded along with the monument location data. The monuments should be tied to a bench mark that is outside the influence of the dam and reservoir. Monuments should be located in areas where they will not be damaged by normal traffic or operations.

3. Piezometric Pressures

A primary indicator of the performance of an embankment is the pore pressure distribution within the structure and its foundation. Pore pressures in embankments are measured by piezometers. There are basically three types of piezometers in common usage: (1) a hydraulic piezometer (open system) in which the water pressure is obtained directly by measuring the elevation of water standing in a pipe or vertical tube; (2) an electronic piezometer (closed system) in which the water pressure deflects a calibrated membrane and the deflection is measured electronically to give the water pressure; and (3) a gas pressure unit (diaphragm system) in which the water pressure is measured by balancing it with pressurized gas in a calibrated unit.

In large high hazard dams, piezometers should be installed to determine the location of the phreatic line and the pressure distribution along a potential failure surface. Piezometers should be installed so that the porous tip is located in the zone of interest within the dam. The line of piezometers should be perpendicular to the longitudinal axis of the embankment. In large structures, there may be several lines of piezometers, while in smaller structures and existing dams perhaps one line of 3-5 piezometers would be adequate.

CHAPTER VI

ANALYSIS OF CONCRETE GRAVITY STRUCTURES

This section applies only to small concrete gravity dams, overflow weirs, sills, and walls on the crest of a dam. It does not apply to concrete gravity dams greater than 50 feet in height, arch dams, or buttress dams. These topics are beyond the scope of this booklet.

A concrete gravity dam is a structure that is designed so that its own weight provides the major resistance to the forces exerted upon it. If the foundation is adequate, and the dam is properly designed and constructed, a solid concrete dam is a permanent structure which requires little maintenance. It is generally constructed of unreinforced blocks of concrete with flexible seals in the joints between the blocks. The most common types of concrete gravity dam failure are overturning or sliding on the foundation.

The foundation for a gravity dam must be capable of resisting the applied forces without overstressing the dam. The horizontal forces on the dam tend to make it slide in a downstream direction, which results in horizontal stresses at the base of the dam. These in turn may try to induce shear failure in the concrete at the base, along the concrete-foundation contact, or within the foundation. Overturning moments result in stresses which may cause crushing of the rock along the toe.

Table 2, 10 CSR 22-3.020 lists stability criteria for conventional concrete dams. The failure mechanisms that must be analyzed include overturning, sliding, structural integrity, and seismic.

A. Forces Acting On The Dam

To analyze the safety of gravity dams, it is necessary to determine the forces which may be expected to affect the stability of the structure. The forces which must be considered are those due to:

1) external water pressure (reservoir and tailwater);
2) internal water pressure (pore pressure or uplift) in the dam and foundation;
3) silt pressure;
4) ice pressure;
5) earthquake;
6) weight of the structure; and
7) forces from gates and other appurtenant structures.

When analyzing the crest of an overflow section, the possibility of subatmospheric pressure developing between the overflowing sheet of water and concrete should be considered. This phenomenon is known as cavitation and can cause serious damage to concrete.

Figure 6.1 shows a nonoverflow concrete section loaded with reservoir water and tailwater. Symbols and definitions for this loading are given below.

Ψ = angle between face of element and the vertical.

T = horizontal distance from upstream edge to downstream edge of section.

I = moment of inertia of base of section 1-foot wide about its center of gravity, equal to $T^3/12$.

w_c = unit weight of concrete.

w = unit weight of water.

h or h' = vertical distance from reservoir water or tailwater, respectively , to base of section.

P or P' = reservoir water or tailwater pressure, respectively, at base of section. It is equal to wh or wh'.

W_o = dead load weight above base of section under consideration including the weight of the concrete, w_c, plus such appurtenances as gates and bridges.

W_w or W'_w = vertical component of reservoir water or tailwater load, respectively, on face above base of section.

M_o = moment of W_o, about center of gravity of base of section.

M_w or M'_w = moment of W_w or W_w' about center of gravity of base of section.

V or V' = horizontal component of reservoir water or tailwater load, respectively, on face above base of section. This is equal to $\frac{wh^2}{2}$ for V and $\frac{w(h')^2}{2}$ for V'.

M_p or M'_p = moment of V or V' about center of gravity of base of section, equal to $\frac{wh^3}{6}$ for M_p and $\frac{w(h')^3}{6}$ for M'_p.

$\sum W$ = resultant vertical force above base of section.

$\sum V$ = resultant horizontal force above base of section.

$\sum M$ = resultant moment of forces above base of section about center or gravity of base of section.

e = distance from midpoint of base of section to point where resultant

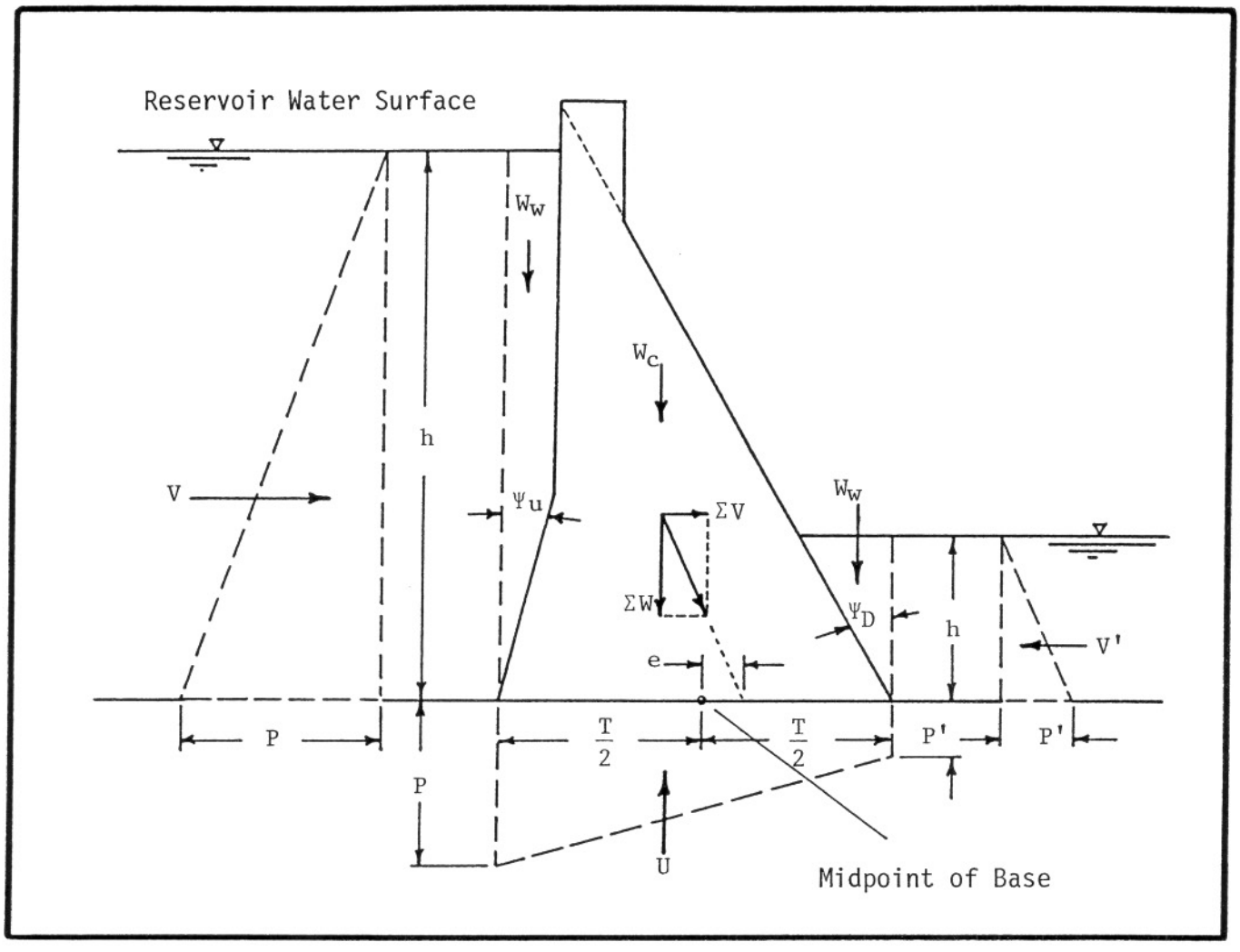


Figure 6.1 Forces Acting on a Concrete Gravity Dam (From Design of Small Dams)

of $\sum W$ and $\sum V$ intersects base of section. It is equal to $\sum M / \sum W$.

U = total uplift force on horizontal section, equal to $T\left(\frac{P+P'}{2}\right)$

The loadings have been summed into horizontal and vertical components, which implies that the foundation or potential failure plane is horizontal or nearly horizontal. If the foundation or potential failure plane is substantially sloped, the loads should be resolved into components normal and parallel to that plane.

1. External Water pressure

External water pressure must be considered on both overflow and nonoverflow sections. Figure 6.1 illustrates water pressure on a nonoverflow section. On the upstream face, the horizontal force is **V** and the vertical force is $\mathbf{W_W}$. The weight of water is generally accepted as 62.4 pounds per cubic foot.

On overflow dams without control features, the total horizontal water pressure on the upstream face is represented by the trapezoid abcd in Figure 6.2. The unit pressures at the top and at the bottom are $62.4h_1$ and 62.4h, respectively. The resultant force passes through the center of gravity of the trapezoid.

The vertical pressure component of water flowing over the top of the spillway is not used in the analysis because most of the total head has changed to velocity head. The sheet of water flowing on the downstream face generally does not exert enough pressure on the dam to warrant consideration. Where tailwater or backwater ponds against the downstream face, it is treated in the same manner as the tailwater in Figure 6.1. The only exception is during major flows when the tailwater pressures are

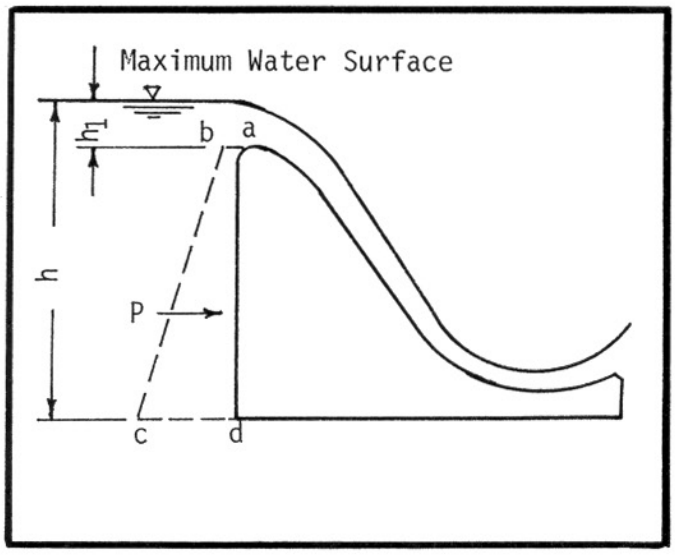


Figure 6.2 Water Pressure on an Overflow Concrete Dam (From Design of Small Dams)

involved in dissipating energy. During this condition, they may contribute only minor stabilizing forces on the dam.

2. Internal Water Pressure

Internal water pressure is an important factor which must be considered on both rock and soil foundations. The intensity of uplift pressure under a concrete dam on a rock foundation is difficult to determine. If the base of the concrete section is not instrumented, it is generally assumed that pore pressures in rock or concrete act over the entire base of the section. It is evident that under sustained loading the uplift pressure at the upstream face is equal to the full reservoir pressure. Its distribution approaches a straight-line variation from this point to the tailwater pressure at the downstream face, or zero if there is no tailwater. This is true not only at the contact between the dam and foundation but within the body of the dam itself. Even if drains are provided to relieve excess hydrostatic pressure, it is still common practice to assume a straight-line pressure distribution from the upstream to downstream toe.

Uplift pressures under a concrete dam on a pervious foundation are related to seepage through permeable materials. Water percolating through pore spaces in the foundation material is affected by frictional resistance in much the same way as water flowing through a pipe. The magnitude and distribution of seepage pressures in the foundation and the amount of underseepage for a given coefficient of permeability can be obtained from a flow net. An excellent reference for flow net construction is given by Cedergren (1977). The intensity of the uplift can be controlled by construction of properly placed aprons, cutoffs, and other devices.

3. Silt pressure

Nearly all streams carry an appreciable amount of silt during flood flows. This is especially true in northern and western Missouri. Where silt is present in a stream on which a concrete dam is built, it will eventually find its way to the reservoir and be deposited adjacent to the dam. If allowed to accumulate against the upstream face of the dam, the saturated silt exerts pressure greater than the hydrostatic pressure of water due to its heavier unit weight. In the absence of reliable test data, a rather common assumption of the magnitude of saturated silt pressure is to consider the horizontal pressure as equivalent to that of a fluid weighing 85 pounds per cubic foot and the vertical weight as 120 pounds per cubic foot.

Many small gravity dams and spillway structures have been designed without regard to silt load. In general, the silt load against storage dams will be a small factor. Against diversion dams, however, it is likely to be more important. In either case there is some basis for neglecting the silt load, especially in the design of concrete spillway weirs and sills.

4. Ice Pressure

Ice pressure is produced by thermal expansion in the ice sheet and by wind drag. The necessary allowance to be made for ice load in the design of a concrete dam is difficult to determine. Data concerning the physical characteristics of ice such as its crushing strength, its modulus of elasticity, and the effects of plastic flow are inadequate and approximate. The thrust exerted by expanding ice depends on the thickness of the sheet, the rate of temperature rise in the ice, fluctuations in the water surface, character of the reservoir shore line, wind drag, and other factors. The rate of temperature rise in the ice is a function of rate of rise of the air temperature and the amount of snow cover on the ice. Lateral restraint of the ice sheet depends on the character of the reservoir shore line.

Because of all these variables, the engineer is faced with a difficult task in estimating the amount of ice pressure acting against a structure. Rose (1947) developed several charts to analyze ice pressure. His charts were reprinted by the U. S. Department of the Interior (1974) in Design of Small Dams and show the thrust in kips for ice thicknesses up to 4 feet and for air temperature rises of 5°, 10°, or 15° F. per hour.

5. Earthquake

Earthquakes impart accelerations to the dam which usually increase the effective loadings on the dam. An allowance for earthquake effects must therefore be made in the analysis of concrete gravity dams and appurtenant structures.

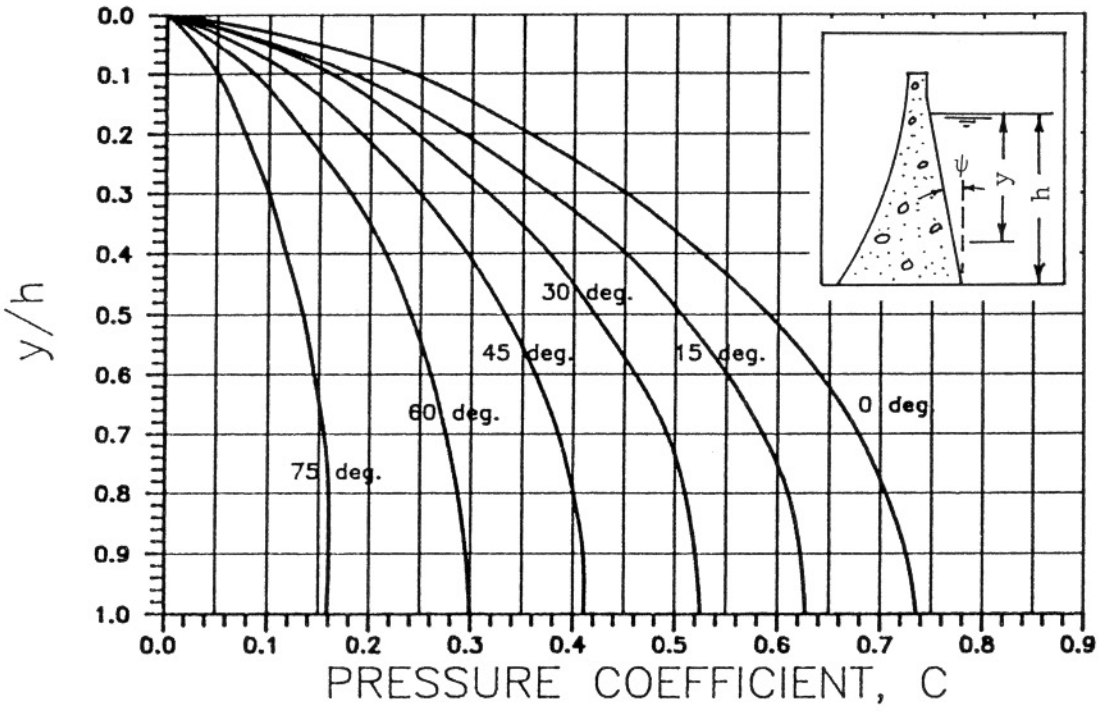


Figure 6.3 Coefficient for Pressure Distribution for Constant Sloping Surfaces

Both vertical and horizontal earthquake loads should be applied in the direction which produces the least stable structure. For the condition of full reservoir this will be a foundation movement in the upstream direction and a foundation movement downward. The upstream movement increases the downstream force of the water and silt loads and produces a downstream inertial force from the mass concrete in the dam. The downward movement decreases the effective weight of the water above a sloping face and of the concrete in the dam. Increasing the horizontal loads in a downstream direction and decreasing the effective weights tend to decrease the stability of the structure. In order to determine the total forces due to an earthquake, the earthquake acceleration must be determined from Table 4, 10 CSR 22-3.020. Table 4 contains horizontal accelerations. Vertical accelerations should be approximated as 50% of the horizontal acceleration.

a. Horizontal Earthquake Force

The effect of inertia on the concrete should be applied at the center of gravity of the mass, regardless of the shape of the cross section. For dams with vertical or sloping upstream faces, the increase in water pressure, P_e, in pounds per square foot, at any elevation due to horizontal earthquake loading is given by Equation 6.1:

$$P_e = C\lambda wh, \qquad (6.1)$$

where

C = a dimensional coefficient giving the distribution and magnitude of pressures;

λ = earthquake intensity (% of gravity);

w = unit weight of water, pcf; and

h = total depth of reservoir at section being studied in feet.

Values of C for various degrees of slope and relations of h and the vertical distance from the reservoir surface to the elevation in question may be obtained from Figure 6.3. The total horizontal force, V_e, above any elevation y distance below the reservoir surface is given by Equation 6.2:

$$V_e = 0.726 P_e y, \qquad (6.2)$$

where

y = the vertical distance from the reservoir surface to the elevation in question in feet.

The total overturning moment, M_e, above elevation y is determined by Equation 6.3:

$$M_e = 0.299 P_e y^2 \qquad (6.3)$$

For dams and structures with a combination vertical and sloping face, the procedure to be used is governed by the relation of the height of the vertical portion to the total height of the dam. If the height of the vertical portion of the upstream face of the dam is equal to or greater than one-half the total height of the dam, it should be analyzed as if it is vertical throughout. If the height of the vertical portion of the upstream face of the dam is less than one-half of the total height of the dam, the pressures should be determined on a sloping line connecting the point of intersection of the upstream face of the dam and reservoir surface with the point of intersection of the upstream face of the dam and the foundation.

b. Vertical Earthquake Force

On sloping faces of dams the weight of the water above the slope should be modified by the appropriate acceleration factor. The weight of the concrete also should be modified by this acceleration factor.

6. Weight of Structure

The weight of the structure includes the weight of the concrete plus appurtenances such as gates and bridges. For most low dams and other concrete structures, only the dead load due to the weight of the concrete is used in the analysis. The unit weight of concrete is considered to be 150 pounds per cubic foot. The total weight acts vertically through the center of gravity of the cross section.

B. Requirements for Stability

A concrete gravity structure must be designed to resist, with ample factor of safety, three failure conditions: overturning, sliding, and overstressing.

1. Overturning

There is a tendency for a gravity structure to overturn about the downstream toe at the foundation or about the downstream edge of any horizontal section. If the vertical stress at the upstream edge of any horizontal section computed without uplift exceeds the uplift pressure at that point, the dam is considered safe against overturning. The most critical condition for inducing overturning is when, at the upstream face, the uplift pressure exceeds the vertical stress at any horizontal section. To perform an analysis of this condition, a combined pressure diagram must be developed.

Under stable conditions the resultant of the horizontal and vertical loads on the structure will be balanced by an equal and opposite force which constitutes the reaction of the foundation. The vertical reaction of the foundation, computed without uplift, is represented by the trapezoid A12B in Figure 6.4B. The vertical normal stresses A1 and B2 are determined by the use of eccentric loading formulas as shown in Equations 6.4 and 6.5:

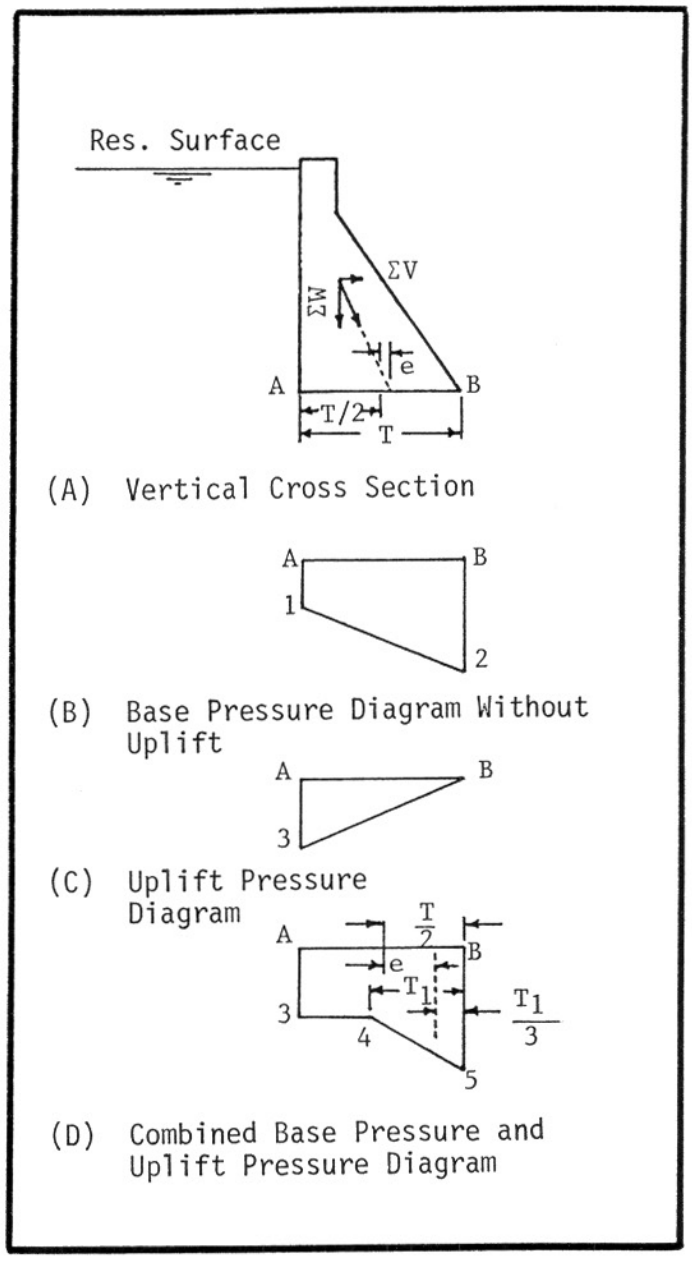


Figure 6.4 Foundation Base Pressures for a Concrete Gravity Dam (From Design of Small Dams)

$$A1 = \frac{\sum W}{T}\left(1 - \frac{6e}{T}\right) \tag{6.4}$$

$$B2 = \frac{\sum W}{T}\left(1 + \frac{6e}{T}\right) \tag{6.5}$$

When uplift is introduced and the uplift pressure at the upstream face is less than A1, compression exists on the

upstream face. When the uplift at A is greater then A1, the upstream face is in tension and cracking will occur. To analyze this condition, the foundation pressure diagram must be revised. The following procedure is used:

(1) A horizontal crack is assumed to exist and extend from the upstream face toward the downstream face to a point where the vertical stress of the adjusted diagram is equal to the uplift pressure at the upstream face. This is point 4 in Figure 6.4D.
(2) Taking moments about the center of gravity of the base, the following equations are obtained:

$$e' = \frac{\sum M}{\sum W - A3 \cdot T}, \qquad (6.6)$$

$$T_1 = 3\left(\frac{T}{2} - e'\right), \qquad (6.7)$$

$$B5 = \frac{2(\sum W - A3 \cdot T)}{T_1} + A3, \qquad (6.8)$$

where
e' = eccentricity of the stress diagram after cracking;
$\sum M$ = summation of moments of all forces;
$\sum W$ = summation of vertical forces;
$A3$ = internal hydrostatic pressure at the upstream face;
T = thickness of section at base; and
T_1 = remaining uncracked portion of the structure.

If B5 is less than the allowable stress for the concrete in any horizontal section or less than the allowable stress in the concrete and foundation for a horizontal section at the foundation, the dam is considered to be safe against overturning.

2. Sliding

The horizontal force, $\sum V$, in Figure 6.4A tends to displace the dam in a horizontal direction. This tendency is resisted by the shear resistance of the concrete or the foundation.

The shear friction factor of safety is the sliding stability criterion for all concrete dams and should generally be used for other structures on rock foundations. The shear friction factor of safety, Q, is shown in Equation 6.9:

$$Q = \frac{cA + (\sum W - U)\tan\phi}{\sum V}, \qquad (6.9)$$

where
c = cohesion value of concrete or foundation;
A = area of base considered; and
$\tan\phi$ = coefficient of internal friction of concrete or foundation.

The values of cohesion and internal friction of the rock or rock-concrete contact must generally be determined by special laboratory tests. For certain rock types, free from adverse geologic structures, cohesion and internal friction can be estimated from published test data. Rock with infilled jointing or lamination and other adverse geologic structures require investigation and testing of the properties of the rock surfaces and infilling material.

3. Structural Integrity

The unit stresses in the concrete and foundation must be kept within prescribed maximum values. Normally, the stresses in the concrete of small gravity dams will be so low that a concrete mix designed to meet other requirements such as durability and workability will attain sufficient strength to insure a reasonable factor of safety.

The foundation should be investigated and the maximum allowable stress established. When the foundation consists of soils, the engineering properties of the material should be determined along with the allowable bearing pressure. If there is any doubt as to the proper classification and adequacy of the foundation materials, laboratory tests should be made to determine the allowable bearing pressures.

CHAPTER VII

GEOLOGICAL CONSIDERATIONS

Careful evaluation of geologic conditions at potential lake sites and sound design and construction practices can greatly enhance lake development. It can also save the owner money during the life of the dam.

All dams seep, and below normal rainfall, combined with a high rate of seepage can cause wide fluctuations in lake levels at some reservoirs. When dams are constructed without any borings or consideration for the geological conditions of the lake site, the likelihood that the dam will experience seepage and safety problems increases dramatically. Unfortunately, many owners discover that a geological investigation should have been performed after the dam is built. Seepage and stability problems are frequently linked to geologic conditions. To reduce seepage, it is sometimes necessary to grout the abutments or foundation, construct a new cutoff trench, or construct an impermeable earthern blanket in the reservoir basin. These are all expensive options, particularly if the work is done after the dam is built.

A surface geological evaluation of the proposed lake site should be made by a qualified geologist. The purpose of the visual investigation is to observe geologic conditions that are not evident from maps or reports of previous studies. At the same time, observations can be made of the presence or absence of springs or seeps, the type and thickness of soil, the characteristics of exposed bedrock outcrops, the presence of karst features, and whether the stream is losing or gaining. An excellent source of information for evaluating potential lake sites in Missouri is a booklet entitled, A guide for the geologic and hydrologic evaluation of small lake sites in Missouri, written by Dean, Barks, and Williams (1976).

The Rules and Regulations of the Missouri Dam and Reservoir Safety Council require engineers to submit exploration records and test results for all new dams that will be regulated under the dam safety law. The exploration records are normally in the form of boring logs which detail the strata and composition of the foundation and abutments at the lake site. The regulations do not specify the type or number of borings.

Typically, an owner will request his engineer to obtain borings at 100-200 foot intervals along the proposed dam centerline across the valley. The actual interval will depend on local conditions and the length of the proposed dam. There should be at least one hole in each abutment and two of the valley holes should extend 10 to 20 feet into bedrock. Backhoe pits can be excavated in potential borrow areas to determine the type and quantity of material available to construct the dam. Care must be taken in obtaining samples from the borrow areas to determine the strength of the soil that will be used in the dam. As pointed out in Chapter V, soil does not have predictable strength properties like concrete or steel. It must be tested at the density at which it will be placed to determine its strength. Construction permits issued by the Dam and Reservoir Safety Program require that density testing of the fill be performed during construction. This requirement is made to insure that the material is placed in accordance with the design specifications.

A. Core Trench Requirements

It is common practice to construct a core trench to control seepage beneath new dams. Subsurface borings give the engineer an indication of how deep the core trench will have to be and how much material must be removed. If the core trench extends to bedrock, the engineer should evaluate the rock strata to insure that the trench has penetrated all weathered rock and the underlying material is free from undesirable geological features.

An understanding of the weathering process is important. Rock at the earth's surface is continually being broken down by weathering. One of the most common weathering processes is the freezing of water in cracks accompanied by expansion of the ice and subsequent fracturing of the rock. Numerous cycles of freezing and thawing can produce extensive weathering.

The flow of water through rock can weaken some minerals and leave the remainder susceptible to wind or water erosion. The broken particles resulting from the weathering process are often transported by air, ice, water, or gravity and redeposited. The modes of deposition can be extremely variable and can cause considerable differences in the successive layers of the deposited or sedimentary material. Hence, sedimentary rocks are often characterized by the great variety in the material in the successive layers. Except for the St. Francois mountain region, Missouri's surface bedrock is almost exclusively sedimentary rock.

There are several types of defects that exist in bedrock. Some of the potential defects in a rock foundation include faults, joints, fractures, and bedding planes. An inspection of the core trench during construction can identify problems and insure that they are corrected before the trench is backfilled.

Faults are common in Missouri, but few are active. Faults are ruptures in rock formations and are caused by high-magnitude tectonic forces. Joints in sedimentary

rock are formed as a result of weathering. The primary difference between faults and joints is the method by which they are formed. When portions of a formation move with respect to each other, the discontinuity produced is termed a fault. If there is a discontinuity but no movement has occurred, the break would be called a joint or fracture. The term fracture can refer to a joint or a fault but always denotes a discontinuity in the rock mass.

Water percolating through fractures can alter the mineral of the adjacent rock and in some cases actually dissolve portions of it. This process occurs in many of the carbonate rock formations in southern Missouri and results in a weak, altered material. The solution joint that is produced can be open, closed, or filled with some type of secondary material. In many cases, the secondary material found in the joint is weak clay. Joints generally tend to be more weathered and open near the surface and narrow with increasing depth. Regardless of whether the joints are filled, it is necessary to identify them during the core trench inspection. Foundation leakage can be reduced by washing and then grouting the joints and fractures. Large clay seams and sand zones in the bedrock need to be excavated and backfilled with compacted clay.

Separations between bedding planes are a type of joint primarily associated with sedimentary rock. The shale and sandstone region of west central Missouri has distinct bedding planes. During construction of the core trench, all weathered shale should be removed.

Faulting and jointing in carbonate rocks may contribute to the development of karst conditions. Deposited clay material along such discontinuities may be washed away with increased head. A severe increase in abutment seepage can sometimes occur during the initial filling of the reservoir. This can be associated with the erosion of clay in abutment joints. It is therefore important to construct a good core trench up the abutment walls as well as along the base of the valley.

Glacial materials deposited by Pleistocene continental ice sheets are prevalent in northern Missouri. Varying thicknesses of till and loess characterize this area. The soils are highly erodible and contribute to siltation problems. Common core trench problems include sand-gravel alluvium and buried channels. Unconsolidated, permeable drift soils in foundations and in reservoir areas are likely to create defects in a dam and must be removed. Because of wide variations in the glacial deposits, proposed dam sites should be thoroughly investigated.

Depending on the region of the state, many different types of soil and bedrock may be encountered. It is important to review detailed published geologic and soil maps before beginning an exploration program or excavating a core trench. Maps and other published reports on Missouri geology are available from the Division of Geology and Land Survey, 111 Fairgrounds Road, P.O. Box 250, Rolla, Missouri 65401.

B. Spillways

Open channel spillways can be located in rock or soil. Borings should be conducted to determine the extent of bedrock and soil in the proposed spillway location. Rock cut spillways are generally erosion resistant and require less maintenance than grass lined soil spillways. Excavation of the rock frequently requires the use of explosives. A well trained, experienced blasting contractor should be retained to perform all blasting at new dams and to enlarge rock cut spillways at existing dams. Overblasting can result in the creation of new joints in the underlying bedrock which can lead to seepage and weathering problems during the life of the dam. An experienced blasting contractor can produce rock from the spillway excavation that can be used as riprap for slope protection, discharge channel erosion protection, and toe berms.

A pre-blast and post-blast survey should be conducted when using explosives at an existing dam when homes and other structures are located nearby. In addition, the staff of the Dam and Reservoir Safety Program requires the owner of an existing dam to monitor slope movement and seepage as part of any construction permit which authorizes blasting.

Where bedrock is deep, the spillway channel should either be lined, retaining walls should be constructed, or the soil cut slopes should be designed to be stable. Many different types of soil can be encountered. Soils may be classified by their origin or mode of deposition. The broadest divisions are residual soils and transported soils. Residual soils are formed by in place chemical and physical decomposition of parent rock or soil material. The deeply weathered clays in southern Missouri are an example of residual soils. Transported soils are moved from their original site of deposition by water, gravity, wind, or ice. They can be deposited in water or on land. The loess soils in northern and western Missouri were transported and deposited by wind. Loess is highly erodible and care should be exercised when designing open channel spillways in it.

Colluvium is soil that has been transported downslope on hillsides primarily by the influence of gravity. In addition to gravity, movement of the soil is aided by ice heave, overturning of tree roots, and water. Abutments that are characterized by bent tree trunks, hummocky or irregular slopes, landslide scars, or heterogeneous soil mixtures likely have colluvial materials at their base. Colluvium can be particularly hazardous to existing dams where landsliding may impact the reservoir, spillways, or other appurtenant structures. This is especially true in open channel spillways.

A stability analysis should be conducted of all spillway cut slopes in soil. A slope failure can result in a spillway becoming blocked by slide debris.

CHAPTER VIII

ENGINEERING SURVEYS

Engineering surveys for dam safety include the study and selection of sites for new dams, construction surveying, and the procurement of data for design and analysis. For new construction, engineering surveying is closely allied to the various stages of project development. The American Society of Civil Engineers (1985) published a manual on engineering surveys, which includes a chapter on dam construction. It is a good reference for practicing engineers to use in planning preliminary and design surveys.

A. Site Selection Survey

An engineering survey program for a dam generally originates as a preliminary or reconnaissance study of one or more sites. The preliminary study does not determine the feasibility of a project; it does, however, provide an important source of data for planners and designers of the project to use in making siting and preliminary design determinations.

The preliminary survey and siting procedure begins with the best available contour maps, such as the U.S. Geological Survey 1 in. = 2000 ft (1:24000) scale quadrangle maps. If the maps used are from two or more sources, care must be taken to insure that the vertical datums are compatible. Possible site locations can then be noted on these maps and a limited amount of field work performed to verify the accuracy of the maps at the published scale. Any changes which have taken place subsequent to development of the maps can be noted during a field reconnaisance.

Care must be exercised when using old maps. Several years are involved in the compilation of mass-produced maps, and many years may pass before the maps are revised. Significant changes may have taken place in the area since the maps were compiled, which could seriously impair the accuracy and usefulness of the maps.

10 CSR 22-3.040(1)(A)12 requires engineers to submit topographic surveys with the construction permit application. Once a site has been selected, additional exploration and testing will usually be performed. Unless the project is very small in scope, photogrammetric mapping probably will be the most economical and expedient means for obtaining the necessary large scale, detailed topographic maps for the engineering design and construction operations. The optimum time for obtaining the photography for mapping is the time interval from January through early April. This is primarily due to the better sun angle and absence of foliage on the trees. The project may have areas obscured by dense tree or underbrush cover in the summer and early fall. Information derived from the geological investigation of the site should be plotted on the photogrammetric map. This includes the location of borings and test pits for future reference.

It is important to establish baselines and temporary benchmarks at an early stage of the design. A horizontal and vertical control survey net should control all five survey programs: preliminary, engineering design, property acquisition, construction, and post-construction. Adequate horizontal and vertical control survey monumentation should be provided to carry the project through the construction stage. Vertical control should be based on the North American Vertical Datum of 1929 where possible. Location of the monumentation on or near the final right-of-way lines generally will serve best to preserve them from disturbance or destruction during construction. In addition, the monumentation should be designed to accommodate post-construction maintenance and control needs such as monitoring the performance or movement of the structure throughout its useful life.

Information obtained from the engineering design survey will be used to layout the core trench, the dam, the spillways, and all appurtenant works in the drawings and during construction staking. Borrow pit location, access roads, material and equipment storage areas, and diversion channels will be delineated on the plans and tied to established baselines. Suitable map scales for reservoir areas and large dam sites will vary with the size of the reservoir areas and roughness of the terrain. Maps for design drawings and structural details may be needed at scale ratios of 1 in. = 10 ft. (1:120) to 1 in. = 100 ft. (1:600). Aerial photography of these particular structural design areas, at the proper altitude for the desired special photogrammetric mapping, should be obtained at the same time as the photography for the overall mapping.

In planning the survey program for the engineering and design phase of project development, consideration must also be given to property acquisition, construction, and post-construction survey programs. This will avoid expensive resurveys or even more costly redesign or correction of already completed portions of the project.

The Rules and Regulations of the Dam and Reservoir Safety Council do not require owners to submit boundary surveys of the reservoir or the dam site. Flood easements are the sole responsibility of the owner. Before building a dam, it is advisable for the owner to obtain the written consent of all persons, agencies, or authorities owning property which may be inundated by the dam on a temporary or permanent basis. This will require a determination

of the impoundment area below the top of dam elevation.

B. Construction Surveying

Upon completion of the engineering design for the project, location and construction surveys and monumentation will be required. Dam site centerlines are usually staked for the convenience of the design engineers, but offset reference monuments will be needed to reestablish the centerline location as construction proceeds. These offset reference monuments should carry both horizontal and vertical positions.

If the area is heavily wooded, the control reference line may be located along a roadway, railway, or electric power transmission line clearing which roughly parallels the stream. Offset traverses to the reference line can then be computed in the office and surveyed in the field. Construction control requirements usually involve more than the basic establishment of centerlines and strategically located bench marks. Supplemental control may also be required at many locations around and on a structure for activities such as setting concrete forms and aligning pipes.

Before the embankment is started, original and final excavated topography of the foundation and the core trench should be obtained to prepare as-built drawings following construction. During construction, survey checks should be made from time to time of monuments to detect any horizontal or vertical disturbance which may have been caused by construction equipment.

The execution of the construction surveys may be the responsibility of the owner, the contractor, or it may be a divided responsibility in accordance with the specifications. In some cases, the owner may establish and maintain principal centerline and grade references while the construction contractor performs required layout work and detailed referencing of the construction.

The reference line monumentation should be preserved for use in postconstruction maintenance and control surveys. The location of the core trench, all internal drains, and pipes should be tied to a reference line. The design may include provisions for the contractor to install monitoring instruments in the dam to detect internal changes and horizontal and vertical movement.

Another aspect of construction surveys is height data. Vertical control must be established to determine the elevation of the crest of the dam and the toe. Because the dam safety law only applies to dams that are over 35 feet in height, care must taken to establish the elevation of the toe of the dam for future reference. This is especially true at sites where the owner plans to build a dam less than 35 feet in height. Post-construction grading can obscure the toe and old creekbed after the dam is complete.

In order to obtain a construction permit to build a dam greater than 35 feet in height, hydrological information must be analyzed and submitted. This includes the flow elevation of all spillways, channel profiles and cross sections, the water storage elevation, inlet and outlet works elevations, and stage-storage information for the reservoir. This information is normally included on the plans. It is necessary to know the topography of the dam site to design a spillway system that will keep the dam from being overtopped during the design flood.

C. Analyzing Existing Dams

Dam safety inspections include an engineering survey to obtain data to perform a hydrologic and hydraulic analysis of the dam and to determine the slope of the embankment faces. The survey includes a profile of the crest, a cross section of the embankment at the maximum section, invert elevations of pipes, cross sections of open channel spillways, location and top elevation of dikes along the discharge channel, and dimensions of inlet and outlet structures.

The two most common methods employed by the staff of the Dam and Reservoir Safety Program are stadia surveys and level and tape surveys. The primary benefit of performing a stadia survey is to develop a plan of the dam and spillways. The location of observable defects such as slides, uncontrolled seepage exit points, and cracks can be determined and plotted on a plan view. It also gives the engineer analyzing the dam additional information concerning the location of the spillways and discharge channels in relation to the dam. With the widespread use of electronic distance measuring equipment, this information can be determined in a few hours. Level and tape surveys are adequate for most dams. Because elevations are the most important data for the hydrologic and hydraulic analysis, a level traverse should be completed and closed on the beginning benchmark.

Stationing for the crest profile must be close enough to determine the lowest elevation on the dam. This elevation is the location where water will first overtop the crest. Stations should extend far enough to include all spillways, except in the case of tailings dams where spillways are typically located several hundred feet upstream. Elevations should be rounded off to the nearest 0.05 ft. A higher degree of accuracy is not needed because the results of the overtopping analysis are normally rounded off to the nearest .1 ft. If the crest is crowned or if the crest slopes from one shoulder to the other, the elevations should be taken at the highest point.

The engineer should attempt to tie the survey to a National Geodetic Vertical Datum (NGVD) but that is not always possible. When an assumed elevation is used, a temporary benchmark should be established near the dam at a location that will remain undisturbed if modifications are required. A nail or spike in a tree near the dam works well. All references to the benchmark should be labeled "local datum". Because the stage-storage curve will be derived from USGS maps, the survey should include the local normal pool elevation which can be related to a reservoir elevation on the map. It is good practice to include an

equation in the inspection report for converting local survey elevations to the elevations on the topographic map.

The engineer should obtain a cross section of the embankment at the maximum section to establish the height of the dam and determine the upstream and downstream slopes. At dams where the old steambed has been covered, it may be necessary to take several elevations along the toe to determine the lowest point in accordance with 10 CSR 22-1.020(59). The station of the embankment cross section should be noted and the engineer should obtain enough points to plot the cross section in the inspection report.

The invert elevations or flow lines of all pipes, inlet structures, and outlet structures should be determined. This information will be used to rate the spillways and establish the water storage (normal pool) elevation. Dimensions and elevations of inlet structures are very important. It may be necessary to make soundings in a deep drop inlet structure to determine the upstream flow line of the discharge pipe.

The final phase of the engineering survey involves open channel spillways. Figure 4.5 shows a plan of a typical open channel emergency spillway. In order to determine the capacity of the channel and derive the water surface profile, a backwater analysis is required. The purpose of the backwater analysis is to rate the channel, determine the location of the control, determine the velocities expected in the channel, and compute the depth of water throughout the channel during the design flood. The term "control" applies to the channel section that regulates discharge. This cannot be determined visually. In fact, the location of the control can change with increasing discharge. Therefore, enough cross sections must be obtained to rate the channel at several discharges.

After the highest elevation in the channel is determined, cross sections should be laid out on the ground. Elevations should be taken at every break in slope and distances measured between each point. The left bank, right bank, and center of channel distances must be determined between each cross section. The bank elevations should extend to the top of dam elevation or to the top of training berms and dikes. The training berm information will be used to determine if it will be overtopped during the spillway design flood.

The survey notes should include information about the type of surface in the spillway. The information should be sufficient to estimate the roughness of the channel at each cross section.

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APPENDIX A

PERMIT FORMS

APPLICATION FOR CONSTRUCTION PERMIT

DATE_____

PART I: GENERAL INFORMATION

Owner(s) Name:_____

Address:_____

_____ Zip_____

Phone:_____

Name of Dam:_____I.D. No. MO_____

County _____

Location of Dam Centerline at Maximum Section:_____

Sect._____, Twp._____North, Rg._____;

Approximate UTM Coordinates_____N _____E

Dam Height:_____ Reservoir Area:_____

Owner's Engineer_____Reg. No._____

Address:_____

_____Zip:_____

Phone: _____

ATTACHED DOCUMENTS (Note: This Application is Not Complete Without Parts II and III)

PART II: DESIGN REPORT CONSIDERATIONS*

PART III CONSTRUCTION DOCUMENTS*

SUBMIT TO: Dam and Reservoir Safety Program
Division of Geology & Land Survey
Department of Natural Resources
P.O. Box 250
Rolla, Missouri 65401

* See Rules and Regulations for Clarification

APPLICATION FOR SAFETY PERMIT

DATE_____ _____

PART I: GENERAL INFORMATION

Owner(s) Name: _____

Address: _____

_____ Zip: _____

Phone: _____

Name of Dam: _____ I.D. No. MO_____

County _____

Location of Dam Centerline at Maximum Section:

Sect._____, Twp._____ North, R_____;

Approximate UTM Coordinates_____

Dam Height:_____ Reservoir Area:_____

Owner's Engineer_____ Reg.No._____

Address: _____

_____ Zip_____

Phone: _____

ATTACHED DOCUMENTS: (Note - This Application is Not Complete Without Addressing Part II)

PART II: AS-BUILT PLANS*.

SUBMIT TO: Dam and Reservoir Safety Program
Division of Geology and Land Survey
Department of Natural Resources
P.O. Box 250
Rolla, Missouri 65401

* See Rules and Regulations for Clarification

APPLICATION FOR REGISTRATION PERMIT

DATE_____

PART I: GENERAL INFORMATION

Owner(s) Name:_____

Address:_____

_____Zip_____

Phone:_____

Name of Dam:_____I.D. No. MO_____

County_____

Location of Dam Centerline at Maximum Section:_____

Sect._____, Twp._____North, Rg._____;

Approximate UTM Coordinates _____N _____E

Dam Height:_____ Reservoir Area:_____

Owner's Engineer_____Reg. No._____

Address:_____

_____ Zip:_____

Phone: _____

ATTACHED DOCUMENTS (Note: This Application is Not Complete Without Parts II thru VI)

PART II: REQUIRED CERTIFICATIONS BY ENGINEER*

PART III INSPECTION REPORT*

PART IV REPORT ON CORRECTION OF DEFECTS (if applicable)*

PART V PROPOSED OPERATION AND MAINTENANCE PLAN*

PART VI REPORT ON CONSTRUCTION SEQUENCE**

SUBMIT TO: Dam and Reservoir Safety Program
Division of Geology & Land Survey
Department of Natural Resources
P.O. Box 250
Rolla, Missouri 65401

* See Rules and Regulations for Clarification
** For Industrial Water Retention Dams only

ATTACHMENT

CONSTRUCTION PERMIT APPLICATION

DAM NAME _____ **ID #** MO _____

COUNTY _____ **DATE** _____

OWNER CERTIFICATION

I, the undersigned, owner, whose Post office Address is _____ _____, Zip _____, do hereby accept and approve these plans.

_____

Owner

ENGINEER CERTIFICATION

I hereby certify that these plans for the (construction of, or alteration of) the _____ _____(Name of Dam) were prepared by me or under my direct supervision for the owners thereof.

_____

(Name of Firm)

_____

(Registered Engineer and P.E. #)

(Engineer's Seal)

ATTACHMENT

SAFETY PERMIT APPLICATION

DAM NAME _____ **ID #** MO _____

COUNTY _____ **DATE** _____

☐ **ENGINEER CERTIFICATION**

I hereby certify that the construction of the _____ _____(Name of Dam) was substantially in accordance with the approved plans and specifications on file with the Missouri Dam and Reservoir Safety Program.

_____

(Name of Firm)

_____

(Registered Engineer and P.E. #)

(Engineer's Seal)

ATTACHMENT

REGISTRATION PERMIT APPLICATION

DAM NAME _____ ID # MO _____

COUNTY _____ DATE _____

☐ **ENGINEER CERTIFICATION**

I hereby certify that I have inspected the _____ _____(Name of Dam) on _____ (Date) in accordance with the law.

☐ **ENGINEER CERTIFICATION**

I hereby certify that the owner of the _____ _____(Name of Dam) has complied with my recommendations to correct observed defects as required by law.

☐ **JUDGEMENT OF STABILITY**

At the time of my inspection, there were no observable indications that the dam was unsafe.

_____

(Name of Firm)

_____

(Registered Engineer and P.E. #)

(Engineer's Seal)

APPENDIX B

INVENTORY FORMS

DAM INVENTORY QUESTIONNAIRE

I.D. # MO __ __ __ __ __

1. NAME OF DAM: _____

2. OWNER: _____

OWNER'S ASSOCIATION: _____

ADDRESS: _____

CITY: _____ STATE: _____ ZIP: _____

PHONE: _____

. LOCATION OF DAM: COUNTY: _____

Township: _____N; Range: _____East/West; Section: _____1/4 _____1/4 _____

. NAME OF ENGINEER: _____

. NAME OF BUILDER OR CONTRACTOR: _____

. TYPE OF DAM: (CHECK BOXES THAT APPLY)

☐ EARTH ☐ ROCK OR ROCK FILL ☐ CONCRETE OR MASONRY ☐ TAILINGS

. USE OF LAKE: (CHECK BOXES THAT APPLY)

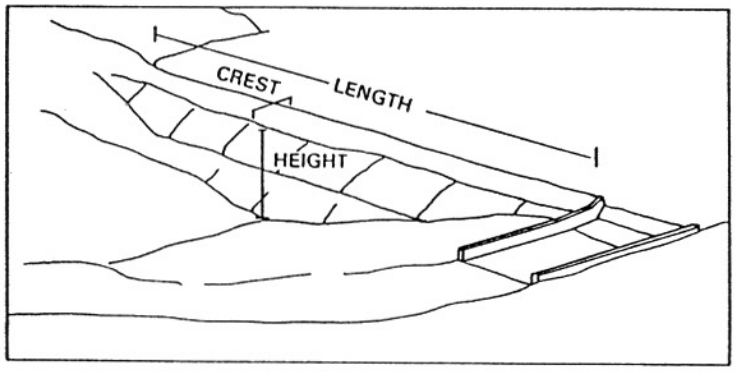
☐ RECREATION (FISHING,SWIMMING, ETC.) ☐ LIVESTOCK WATERING ☐ WATER SUPPLY

☐ CROP IRRIGATION ☐ INDUSTRIAL

. YEAR DAM WAS BUILT: _____

. SURFACE AREA OF LAKE: _____ ACRES

. DIMENSIONS OF DAM: (FILL IN BLANKS ON SKETCH)



HEIGHT: _____

WIDTH OF CREST: _____

LENGTH OF DAM: _____

. PRIMARY SPILLWAY? ☐ YES ☐ NO

. EMERGENCY SPILLWAY? ☐ YES ☐ NO

. NAME OF PERSON FILLING OUT QUESTIONNAIRE:

_____

DATE: _____

AGRICULTURAL EXEMPTION INFORMATION SHEET

MISSOURI DAM & RESERVOIR SAFETY PROGRAM

NAME OF DAM: _____ ID# (MO_____)

OWNER: _____

ADDRESS: _____

CITY: _____ STATE: ____ ZIP: _____ PHONE ___/_____

TYPE OF DAM: ☐ EARTH ☐ ROCK FILL ☐ CONCRETE/MASONRY

☐ OTHER _____

USE OF LAKE: (Check all boxes that apply)

☐ RECREATION (FISHING, SWIMMING, ETC.) ☐ LIVESTOCK WATERING

☐ WATER SUPPLY ☐ FISH REARING ☐ CROP IRRIGATION ☐ INDUSTRIAL

CURRENT NUMBER OF LIVESTOCK ON FARM THAT RECEIVE WATER FROM LAKE:

HORSES ____ HOGS ____ CATTLE ____ SHEEP ____ OTHER ____

METHOD OF WATERING LIVESTOCK:

☐ DIRECT ACCESS TO LAKE ☐ WATERING TANK ☐ OTHER

FARM SIZE (acres): TOTAL ____ PASTURE ____ HAY ____ WOODLAND ____ CROP ____

NUMBER OF FISH RAISED AND SOLD LAST YEAR:

CATFISH _____ TROUT _____ CARP _____ OTHER _____

ARE FISH RAISED IN CONFINEMENT CAGES? ☐ OR HARVESTED BY SEINING? ☐

NUMBER OF ACRES IRRIGATED AND TYPE OF CROPS:

CORN ____ AC. SOYBEANS ____ AC. MILO ____ AC. HAY ____ AC.

OTHER _____

TYPE OF IRRIGATION EQUIPMENT: TRAVELING GUN ☐ CENTER PIVOT ☐

STATIONARY SPRINKLER ☐ FLOOD IRRIGATION ☐

PUMPING FROM LAKE ☐ GRAVITY WITHDRAWAL FROM LAKE ☐

NAME OF PERSON FILLING OUT THIS QUESTIONNAIRE: _____

_____

DATE: _____ COMMENTS: _____

_____

APPENDIX C

RAINFALL DATA FOR MISSOURI

TABLE C.1

Precipitation Values for Counties in Missouri

County	6-Hour Duration			12-Hour Duration			24-Hour Duration		
	50-Year	100-Year	PMP*	50-Year	100-Year	PMP*	50-Year	100-Year	PMP*
Adair	4.8	5.2	27.1	5.5	6.3	32.0	6.4	7.0	33.5
Andrew	5.0	5.4	27.0	5.9	6.6	32.0	6.6	7.3	33.8
Atchison	4.9	5.3	26.7	5.9	6.4	31.6	6.4	7.1	33.2
Audrain	4.8	5.2	27.7	5.6	6.3	32.9	6.5	7.2	34.5
Barry	5.5	6.0	28.9	6.5	7.2	34.4	7.6	8.4	37.8
Barton	5.4	6.0	28.4	6.4	7.1	33.9	7.4	8.2	36.5
Bates	5.3	5.8	28.0	6.2	7.0	33.3	7.2	8.0	35.6
Benton	5.1	5.7	28.1	6.0	6.8	33.4	7.0	7.7	35.6
Bollinger	4.8	5.2	28.7	5.6	6.2	34.0	6.6	7.2	36.5
Boone	4.9	5.3	27.7	5.7	6.4	33.0	6.6	7.3	34.7
Buchanan	5.0	5.5	27.2	6.0	6.7	32.2	6.7	7.4	34.0
Butler	4.9	5.4	28.9	5.8	6.4	34.5	6.7	7.4	37.3
Caldwell	5.0	5.4	27.3	5.9	6.6	32.3	6.7	7.4	34.1
Callaway	4.9	5.3	27.8	5.7	6.4	33.1	6.6	7.3	34.8
Camden	5.0	5.6	28.2	6.0	6.7	33.6	7.0	7.7	36.0
Cape Girardeau	4.8	5.1	28.6	5.5	6.1	34.0	6.5	7.1	36.2
Carroll	5.0	5.4	27.4	5.8	6.6	32.7	6.7	7.4	34.3
Carter	5.0	5.5	28.8	5.8	6.5	34.3	6.8	7.5	37.0
Cass	5.2	5.7	27.8	6.1	6.9	33.1	7.1	7.9	35.0
Cedar	5.3	5.9	28.3	6.3	7.0	33.8	7.3	8.0	36.3
Chariton	4.9	5.3	27.4	5.7	6.4	32.5	6.6	7.3	34.2
Christian	5.3	5.9	28.8	6.3	7.0	34.3	7.3	8.0	37.4
Clark	4.6	5.1	27.0	5.4	6.0	31.8	6.2	6.8	33.2
Clay	5.1	5.6	27.4	6.0	6.7	32.7	6.8	7.6	34.4
Clinton	5.0	5.5	27.3	5.9	6.7	32.3	6.7	7.4	34.1
Cole	4.9	5.4	28.0	5.8	6.5	33.3	6.8	7.4	35.2
Crawford	5.9	5.3	28.3	5.7	6.4	33.6	6.6	7.4	35.9
Cooper	5.0	5.4	27.7	5.9	6.6	33.1	6.8	7.5	35.0
Dade	5.3	5.9	28.5	6.3	7.0	33.9	7.4	8.1	36.7
Dallas	5.2	5.7	28.4	6.1	6.8	33.8	7.1	7.8	36.5
Daviess	4.9	5.4	27.1	5.8	6.5	32.0	6.5	7.2	33.8
Dekalb	5.0	5.4	27.1	5.9	6.6	32.1	6.6	7.3	33.8
Dent	4.9	5.4	28.5	5.8	6.5	33.9	6.7	7.5	36.3
Douglas	5.2	5.8	28.8	6.2	6.9	34.3	7.1	7.9	37.5
Dunklin	4.9	5.4	29.1	5.8	6.4	34.8	6.8	7.5	38.0
Franklin	4.8	5.2	28.0	5.6	6.3	33.3	6.5	7.2	35.1
Gasconade	4.8	5.3	28.0	5.7	6.3	33.3	6.6	7.3	35.1
Gentry	4.9	5.3	26.9	5.8	6.5	31.8	6.5	7.2	33.5
Greene	5.3	5.9	28.6	6.3	7.0	34.0	7.3	8.0	37.0
Grundy	4.9	5.3	27.1	5.7	6.4	32.0	6.5	7.1	33.6
Harrison	4.9	5.3	26.9	5.7	6.4	31.8	6.4	7.1	33.3
Henry	5.2	5.7	28.0	6.1	6.9	33.3	7.1	7.8	35.5
Hickory	5.2	5.7	28.2	6.1	6.8	33.7	7.1	7.8	36.0
Holt	5.0	5.4	26.9	5.9	6.5	31.9	6.5	7.2	33.5

TABLE C.1

Precipitation Values for Counties in Missouri

County	6-Hour Duration			12-Hour Duration			24-Hour Duration		
	50-Year	100-Year	PMP*	50-Year	100-Year	PMP*	50-Year	100-Year	PMP*
Howard	4.9	5.3	27.6	5.7	6.5	32.9	6.7	7.4	34.5
Howell	5.1	5.7	28.9	6.0	6.8	34.5	7.0	7.8	37.5
Iron	4.9	5.3	28.5	5.7	6.3	33.8	6.6	7.3	36.2
Jackson	5.1	5.7	27.5	6.1	6.8	33.0	6.9	7.7	34.8
Jasper	5.5	6.0	28.5	6.5	7.2	34.0	7.5	8.3	37.0
Jefferson	4.8	5.2	28.1	5.5	6.1	33.3	6.4	7.1	35.2
Johnson	5.1	5.6	27.8	6.0	6.8	33.1	7.0	7.7	35.0
Knox	4.7	5.2	27.1	5.4	6.2	32.0	6.3	7.0	33.5
Laclede	5.1	5.7	28.4	6.0	6.7	33.8	7.0	7.7	36.4
Lafayette	5.1	5.6	27.6	6.0	6.7	32.9	6.9	7.6	34.8
Lawrence	5.4	6.0	28.6	6.4	7.1	34.1	7.4	8.2	37.1
Lewis	4.7	5.1	27.2	5.4	6.1	32.0	6.2	6.9	33.6
Lincoln	4.7	5.1	27.7	5.5	6.1	32.9	6.4	7.0	34.4
Linn	4.9	5.3	27.2	5.7	6.4	32.2	6.5	7.2	33.9
Livingston	4.9	5.4	27.5	5.8	6.5	32.2	6.6	7.3	34.0
McDonald	5.5	6.1	28.9	6.6	7.4	34.4	7.7	8.5	37.9
Macon	4.8	5.2	27.2	5.6	6.3	32.3	6.4	7.1	33.9
Madison	4.8	5.3	28.6	5.6	6.2	33.9	6.6	7.3	36.2
Maries	4.9	5.4	28.2	5.8	6.5	33.5	6.8	7.5	35.7
Marion	4.7	5.1	27.3	5.4	6.1	32.2	6.3	7.0	33.9
Mercer	4.8	5.3	26.9	5.6	6.3	31.8	6.4	7.0	33.3
Miller	5.0	5.5	28.1	5.9	6.6	33.5	6.9	7.5	35.8
Mississippi	4.8	5.1	28.9	5.5	6.1	34.2	6.5	7.1	37.0
Moniteau	5.0	5.4	27.9	5.9	6.6	33.2	6.8	7.5	35.0
Monroe	4.8	5.2	27.5	5.6	6.3	32.6	6.4	7.1	34.1
Montgomery	4.8	5.2	27.7	5.6	6.3	33.0	6.5	7.1	34.7
Morgan	5.0	5.5	28.0	6.0	6.7	33.3	6.9	7.6	35.5
New Madrid	4.8	5.3	29.0	5.6	6.2	34.5	6.6	7.2	37.2
Newton	5.5	6.1	28.7	6.5	7.3	34.2	7.6	8.4	37.5
Nodaway	4.9	5.3	26.8	5.8	6.5	31.6	6.4	7.1	33.3
Oregon	5.0	5.6	28.9	6.0	6.7	34.5	6.9	7.7	37.6
Osage	4.9	5.4	28.0	5.7	6.4	33.3	6.7	7.4	35.2
Ozark	5.2	5.8	28.9	6.2	6.9	34.5	7.2	7.9	37.8
Pemiscot	4.9	5.3	29.2	5.7	6.4	34.8	6.7	7.4	38.0
Perry	4.8	5.1	28.5	5.5	6.1	33.7	6.4	7.1	36.0
Pettis	5.0	5.6	27.8	6.0	6.7	33.2	7.0	7.6	35.0
Phelps	4.9	5.4	29.3	5.8	6.5	33.7	6.8	7.5	36.0
Pike	4.7	5.1	27.6	5.4	6.1	32.7	6.3	7.0	34.0
Platte	5.1	5.6	27.3	6.0	6.7	32.5	6.8	7.6	34.3
Polk	5.2	5.8	28.4	6.2	6.9	33.9	7.2	7.9	36.5
Pulaski	5.0	5.5	28.3	5.9	6.6	33.8	6.9	7.6	36.1
Putnam	4.8	5.2	26.9	5.5	6.2	31.8	6.3	7.0	33.2
Ralls	4.7	5.1	27.5	5.4	6.1	32.6	6.3	7.0	34.0
Randolph	4.8	5.3	27.5	5.7	6.4	32.7	6.5	7.2	34.2

TABLE C.1

Precipitation Values for Counties in Missouri

County	6-Hour Duration			12-Hour Duration			24-Hour Duration		
	50-Year	100-Year	PMP*	50-Year	100-Year	PMP*	50-Year	100-Year	PMP*
Ray	5.0	5.5	27.4	5.9	6.7	32.7	6.8	7.5	34.4
Reynolds	4.9	5.4	28.7	5.8	6.4	34.0	6.7	7.4	36.5
Ripley	5.0	5.5	28.9	5.9	6.6	34.5	6.8	7.5	37.5
St. Charles	4.7	5.1	27.8	5.5	6.1	33.0	6.4	7.0	34.7
St. Clair	5.2	5.8	28.2	6.2	6.9	33.5	7.2	7.9	36.0
St. Francois	4.8	5.2	28.4	5.6	6.2	33.6	6.5	7.2	35.9
St. Louis	4.7	5.1	27.9	5.4	6.1	33.1	6.3	7.0	34.8
St. Louis City	4.7	5.1	27.9	5.4	6.0	33.0	6.3	7.0	34.8
Ste. Genev	4.8	5.1	28.3	5.5	6.1	33.6	6.5	7.1	35.8
Saline	5.0	5.4	27.6	5.9	6.6	33.0	6.8	7.5	34.6
Schuyler	4.7	5.2	26.9	5.5	6.2	31.8	6.3	6.9	33.2
Scotland	4.7	5.1	26.9	5.4	6.1	31.8	6.2	6.9	33.2
Scott	4.8	5.2	28.8	5.6	6.1	34.1	6.5	7.1	36.6
Shannon	5.0	5.5	28.7	5.9	6.6	34.2	6.8	7.6	37.0
Shelby	4.8	5.2	27.3	5.5	6.2	32.3	6.4	7.0	33.9
Stoddard	4.8	5.3	28.9	5.7	6.3	34.3	6.6	7.3	37.0
Stone	5.4	6.0	28.9	6.4	7.1	34.5	7.5	8.2	37.7
Sullivan	4.8	5.3	27.0	5.6	6.3	32.0	6.4	7.1	33.5
Taney	5.3	5.9	28.9	6.3	7.0	34.5	7.4	8.1	37.8
Texas	5.0	5.6	28.6	6.0	6.7	34.0	6.9	7.6	37.0
Vernon	5.4	5.9	28.2	6.3	7.1	33.6	7.3	8.1	36.0
Warren	4.8	5.2	27.9	5.5	6.2	33.1	6.5	7.2	34.8
Washington	4.8	5.3	28.3	5.6	6.3	33.6	6.6	7.3	35.8
Wayne	4.9	5.3	28.7	5.7	6.3	34.1	6.7	7.4	36.8
Webster	5.2	5.8	28.6	6.2	6.9	34.0	7.2	7.9	37.0
Worth	4.9	5.3	26.8	5.7	6.4	31.6	6.4	7.0	33.3
Wright	5.1	5.7	28.6	6.1	6.8	34.0	7.1	7.8	37.0

* Probable Maximum Precipitation (PMP) values were taken from the National Weather Service publication, Hydrometeorological Report 51. All PMP values in Table C.1 are for 10 square mile areas.

ERRATA - October 16, 1989

CORRECTED TABLE C.1 Ray through Wright Counties

Rules of
Department of Natural Resources
Division 22—Dam and Reservoir Safety Council
Chapter 1—Organization, Definitions and Immunity

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Title 10—DEPARTMENT OF NATURAL RESOURCES
Division 22—Dam and Reservoir Safety Council
Chapter 1—Organization, Definitions and Immunity

10 CSR 22-1.010 General Organization

PURPOSE: This rule complies with section 536.023, RSMo which requires each agency to adopt as a rule a description of its operation and the methods where the public may obtain information or make submissions or requests.

(1) Section 236.410, RSMo established a Dam and Reservoir Safety Council of Missouri. The council consists of seven (7) members appointed by the governor with the advice and consent of the senate. The council holds a minimum of four (4) regular meetings each year and special meetings and hearings as the council chairman may deem necessary.

(2) The Missouri dam and reservoir safety law, rules, regulations, guidelines and standards provide for the construction management and operation of dams and reservoirs in a manner which will provide adequate protection of public safety, life or property. To achieve this purpose the council has statutory powers as listed in sections 236.405 and 236.415, RSMo for policy making, adopting rules, standards and guidelines and issuing of permits.

(3) The Department of Natural Resources is authorized under section 236.405, RSMo to administer and enforce all rules, standards and guidelines adopted by the council and to assist the council in achieving its statutory duties. The department has designated the dam and reservoir safety program as the agency within the department responsible for administering the dam and reservoir safety law. The director of the Department of Natural Resources appoints a chief engineer who is the dam and reservoir safety program director and a staff, as provided in section 236.405, RSMo. The chief engineer and staff provide day-to-day operation of the dam and reservoir safety program.

(4) The dam and reservoir safety program performs administrative and technical functions including: review permit applications and recommend approval or denial of applications; inspect dams and reservoirs; enforce the law and all rules, standards and guidelines adopted pursuant to Chapter 236, RSMo; employ necessary staff; develop facts as may be required by the council; recommend rules, standards and guidelines required by Chapter 236, RSMo; mitigate or eliminate unsafe dam or reservoir conditions; and other functions as described in sections 236.420 to 236.500, RSMo.

(5) Requests for permit applications, requirements or other permit information, copies of these rules and the dam and reservoir safety law, dam inspections and technical information and assistance, requests for public hearings and any other submissions are to be made to the Department of Natural Resources, Dam and Reservoir Safety Program, P.O. Box 250, Rolla, MO 65401.

AUTHORITY: Chapter 236, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981.

Original authority: 236.405, RSMo 1979 and 236.415, RSMo 1979.

10 CSR 22-1.020 Definitions

PURPOSE: The following terms when used in rules, standards and guidelines adopted by the Dam and Reservoir Safety Council pursuant to the dam safety law shall have the meaning respectively ascribed to them by this section.

PUBLISHER'S NOTE: The secretary of state has determined that the publication of the entire text of the material which is incorporated by reference as a portion of this rule would be unduly cumbersome or expensive. Therefore, the material which is so incorporated is on file with the agency who filed this rule, and with the Office of the Secretary of State. Any interested person may view this material at either agency's headquarters or the same will be made available at the Office of the Secretary of State at a cost not to exceed actual cost of copy reproduction. The entire text of the rule is printed here. This note refers only to the incorporated by reference material.

(1) Agency engineer means an experienced engineer, not necessarily registered as a professional engineer in Missouri, who works for an engineering division of a state or federal agency regularly engaged in dam and reservoir design and construction for soil and water conservation or irrigation or relating to wildlife conservation.

(2) Agricultural dam means any dam, the primary use of which is to impound water for use in irrigation, livestock watering or commercial fish rearing and sale.

(3) Alterations, repairs, or either means alterations or repairs as affect the safety of a dam or reservoir, or public safety, life or property.

(4) Appurtenant works means the structures or materials incident to or annexed to dams which are built or maintained in connection with dams and which are used primarily in connection with their proper operation, maintenance or functioning. This includes, without limitation, structures as spillways, either in the dam or separate therefrom; the reservoir rim; low level outlet works; and water conduits such as tunnels, pipelines or penstocks, either through a dam or its abutments.

(5) Area capacity curves means graphic curves which show the relationship between reservoir surface area and the storage capacity of the reservoir at given elevations.

(6) Chief engineer means the head of the dam and reservoir safety program of the Department of Natural Resources or his/her representative.

(7) Commercial fish rearing reservoir means a reservoir which was designed specifically for fish rearing purposes and the primary use is to provide water for commercial fish rearing and sale to other parties in a for profit venture. This does not include activities such as sport fishing.

(8) Construction permit means a written authorization issued by the council giving the owner the right to construct, alter, enlarge, reduce, repair or remove a dam or reservoir or appurtenances thereto, with conditions that are necessary to adequately protect the public safety, life, property, the dam or reservoir.

(9) Conventional dam means any dam other than an industrial water retention dam.

(10) Council delegate or authorized representative means an individual, usually the chief engineer, authorized by the council to act in its behalf.

(11) Crest or dam crest means the top surface of the dam.

(12) Crest elevation or dam crest elevation means the lowest elevation of the crest exclusive of the spillway(s).

(13) Dam means any artificial or man-made barrier which does or may impound water and which impoundment has or may have a surface area of fifteen (15) or more acres of water at the water storage elevation or which is thirty-five feet (35') or more in height from the natural bed of the stream or watercourse or lowest point on the toe of the dam (whichever is lower) up to the crest elevation, together with appurtenant works. Sections 236.400 to 236.500 shall not apply to any dam which is not or will not be in excess of thirty-five feet (35') in height or to any dam or reservoir licensed and operated under the Federal Power Act.

(14) Dam and Reservoir Safety Council referred to as the council means seven (7) members appointed by the governor for purposes of implementing the dam safety law.

(15) Dangerous dam or reservoir is a dam or reservoir which is in an advanced state of deterioration so that if deterioration continues, the threat of dam failure and flooding would be substantial.

(16) Department means the Department of Natural Resources.

(17) Downstream environment zone means the area downstream from a dam that would be affected by inundation in the event the dam failed when filled to the emergency spillway crest elevation or to the dam crest elevation, in the absence of an emergency spillway.

(18) Earthquake intensity means Modified Mercalli intensity which is used to describe the degree of shaking a dam will experience.

(19) Enforcement order means a written directive issued by the council or the chief engineer to the owner of a dam for correction of defects in the dam or reservoir which have been determined to make the structure a threat to public safety, life or property. The order will contain specific actions with which the owner must comply to remove the threat the dam or reservoir poses to public safety, life or property.

(20) Enlargement means any change in or addition to an existing dam or reservoir, which raises the height of the dam, increases the watershed for the reservoir or raises the water storage elevation of the water impounded by the dam or reservoir.

(21) Environmental class means a classification of the downstream environment zone based on the contents of that zone (see 10 CSR 22-2.040(1)). Class I represents the most severe threat to public safety, life or property and Class III represents the least threat.

(22) Factor of safety means the resultant of the summation of the forces resisting failure divided by the summation of the driving forces tending to cause failure.

(23) Freeboard means the difference in elevation between the dam crest elevation and the water storage elevation in the reservoir.

(24) Height or height of dam means the difference in the elevation of either the natural bed of the stream or watercourse or the lowest point on the toe of the dam (whichever is lower) and the dam crest elevation.

(25) Industrial building means a permanent, enclosed structure used by groups of workers usually involved in some type of manufacturing, processing or industrial related process.

(26) Industrial water retention dam means a dam used to retain the solids transported as water-borne industrial byproducts and the associated water. This includes, but is not limited to, tailings dams, slime impoundments and settling ponds.

(27) Inundation means water, two feet (2') or more deep, over the general level of the submerged ground affected outside the stream channel.

(28) Inspection means scheduled and unscheduled examinations of a dam and reservoir with the primary objective of making safety observations and recording them in a written description.

(29) Irrigation reservoir means a reservoir whose primary use is to provide water for the irrigation of agricultural lands for the production of grains, hay, pasture, fruits, vegetables and animal feeds which are for sale or to be used by the owner.

(30) Law means the dam and reservoir safety law, as contained in Chapter 236, RSMo and all rules, standards and guidelines adopted thereto.

(31) Liquefaction is a condition where a soil will undergo continued deformation at a constant low residual stress or with low residual resistance, due to the build-up and maintenance of high pore water pressures, which reduce the effective confining pressure to a very low value.

(32) Livestock watering reservoir means a reservoir whose primary use is to provide water for livestock which are raised for breeding or marketing purposes.

(33) Maintenance means the proper keeping of all aspects of a dam or reservoir and appurtenances thereto, that pertain to safety, in a state of repair and working order as necessary to comply with the law and any permit issued thereunder and to protect public safety, life or property.

(34) Modification(s) means changes or revisions to the design, construction, maintenance, operation or repair or the alteration, enlargement, reduction, removal or natural physical changes that may occur to a dam or reservoir that were not included in the approved plans for the construction permit, or changes or revisions to a dam or reservoir where a registration or safety permit is in effect or required hereunder, if the changes or revisions would endanger public safety, life or property as a result of creating a potential failure in the dam or reservoir; except that modification(s) do not mean or include approved anticipated enlargements, outlined by design plans and specifications submitted and approved with the original application for a construction, safety or registration permit for industrial water retention dams and reservoirs.

(35) Observable defects are those defects which would be detectable by an experienced professional engineer making an on-site visual inspection of the dam in accordance with current engineering, geologic and construction practices.

(36) Owner or dam owner means a person who owns, controls, operates, maintains, manages or proposes to construct a dam or reservoir including: the state and its departments, institutions, agencies and political subdivisions, but not the United States government; a municipal or quasi-municipal corporation; a district; a public utility; a natural person, firm, partnership, association, corporation, political subdivision or legal entity; the duly authorized agents or leasees, or trustees of any of the foregoing; or receivers or trustees appointed by any court for any of the foregoing.

(37) Permanent dwelling means a dwelling occupied at least ninety (90) days a year.

(38) Permit means construction, safety or registration permit.

(39) Permit applicant or applicant means an owner who applies for a construction, safety or registration permit.

(40) Probable maximum acceleration means the horizontal acceleration developed at a dam as a result of an earthquake with a probability of occurrence similar to the probable maximum precipitation. The probable maximum acceleration is readily available from a Corps of Engineers Report entitled Earthquake Potential of the St. Louis District—Ground Motion Supplement which is on file with the chief engineer of the Dam and Reservoir Safety Program.

(41) Probable maximum precipitation or PMP means the precipitation that may be expected from the most severe combination of critical meteorologic conditions that are reasonably possible in an area. The PMP is readily available from the National Weather Service in Hydrometeorological Report 51, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian.

(42) Public building means a permanent, enclosed structure used by groups of the general public but not necessarily owned by the public.

(43) Registration permit means a permit issued for a period not to exceed five (5) years by the council to the owner of a dam or reservoir in existence or in the progress of construction on August 13, 1981 or which becomes subject to the law for the dams and reservoirs by a change in factors or circumstances subsequent to that date. Permits shall only be issued for dams which are in a properly maintained condition or which have made and complied with recommendation for corrections of observed defects of the dam or reservoir and have been examined and approved in accordance with the law.

(44) Reservoir means any basin, including the water, which contains or will contain the maximum amount of water impounded by a dam.

(45) Safety permit means a permit issued to the owner of a dam for a period of five (5) years, or less if safety considerations so require, by the council indicating that the dam meets the requirements of the law, and containing conditions as to operations, maintenance and repair as are necessary to adequately protect public safety, life and the dam or reservoir.

(46) Seepage means the migration of water through a dam or foundation.

(47) Significant modification means changes, alteration or modifications to an existing dam or changes to the construction documents for a new dam. Those include, but are not limited to: changes in the location of the dam or reservoir, changes in the storage capacity or drainage area, changes in the capacity of the spillway system, modification of the embankment slopes, changes in the height of the dam or structure, or the use of different construction methods or procedures than those submitted with the permit application.

(48) Spillway means any passageway, channel or structure, open or closed or both, designated expressly or primarily to discharge excess water from a reservoir after the water storage elevation has been reached.

(49) Spillway design flood or SDF means the specified flood discharge that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in an area and for which the dam and reservoir are designed. The SDF is derived from the rainfall values given in Table 5.

(Editor's Note: For Table 5 see 10 CSR 22-3.020)

(50) Stability means the properties of a dam or reservoir that cause it when disturbed from a condition of equilibrium to develop forces or moments that restore the original condition.

(51) Starter dam means a pervious or impervious dam constructed as the first phase in the building of an industrial water retention dam and reservoir.

(52) Storage means the volumetric capacity of the reservoir below the water storage elevation or other selected reference on the dam.

(53) Stream means any river, creek or channel, having well-defined banks, in which water flows for substantial periods of the year to drain a given area.

(54) Tailings means the material generated by a mining/milling operation which is deposited in slurry form in an impoundment for storage, disposal, or both.

(55) Tailings dam means an existing dam or reservoir used for the impoundment or retention of tailings or a proposed, existing or newly constructed dam and reservoir for which the anticipated or contemplated use is the impoundment or retention of tailings.

(56) Toe or toe of slope means the line of the fill (dam embankment) slope where it intersects the natural ground.

(57) Water means water, other liquids or tailings.

(58) Watercourse means a valley, swale, depression or other low place in the topography occupied by flowing water during conditions of runoff.

(59) Water storage elevation means that elevation of water surface at the principal spillway which could be obtained by the dam or reservoir were there no outflow and were the reservoir full of water.

(60) Watershed means the area that contributes or may contribute surface water to a reservoir.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed Sept. 1, 1993, effective May 9, 1994.*

**Original authority: 236.405, RSMo 1979, amended 1933 and 236.415, RSMo 1979.*

10 CSR 22-1.030 Immunity of Officers

PURPOSE: The purpose of this rule is to restate the immunity from damages provided in section 236.475, RSMo (1986).

(1) In the absence of willful and wanton misconduct, no action shall be brought against the council, the chief engineer or his/her agents, department employees or private individuals employed as consultants by the department for the recovery of damages caused by the partial or total failure of any dam or reservoir or through the use or operation of any dam or reservoir upon the ground that the person is liable by virtue of any of the following: the approval of a dam or reservoir or permits therefore; the issuance or enforcement of orders relating to maintenance, operation or repair of a dam or reservoir; control or regulation of a dam or reservoir; measures taken to protect against failure during an emergency; or denial of a permit.

AUTHORITY: section 236.475, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981.*

**Original authority: 236.475, RSMo 1979.*

Rules of
Department of Natural Resources
Division 22—Dam and Reservoir Safety Council
Chapter 2—Permits

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Title 10—DEPARTMENT OF NATURAL RESOURCES
Division 22—Dam and Reservoir Safety Council
Chapter 2—Permits

10 CSR 22-2.010 Who Needs a Permit

PURPOSE: This rule identifies those persons who need to obtain a permit for their dam and reservoir and to identify those persons who do not need to obtain a permit for their dam and reservoir.

(1) The owner of a proposed new dam thirty-five feet (35') or more in height is required to obtain a construction permit and a safety permit for his/her dam and reservoir. The owner of an existing dam thirty-five feet (35') or more in height is required to obtain a registration permit within the time set forth in 10 CSR 22-2.020(2).

(2) By definition, the United States government is not considered an owner. Therefore, no federal dam and reservoir is regulated by sections 236.400—236.500, RSMo and no permits are required.

(3) Agricultural dams are exempted from all permit requirements as long as the agricultural dam and reservoir continue to be used primarily for agricultural purposes (see 10 CSR 22-1.020(2)). The owners of agricultural dams and reservoirs over thirty-five feet (35') in height must notify the council of their reliance on this exemption and their basis for application of this exemption to their dams. If an agricultural dam and reservoir is constructed after the effective date of the law, but subsequently becomes subject to the provisions of the law, the owner shall provide, prior to obtaining a registration permit, evidence that the dam meets the construction permit criteria in effect at the time the dam was constructed.

(4) Dams and reservoirs licensed and operated under the Federal Power Act are exempted from all permit requirements.

(5) Dams and reservoirs that were designed by and the construction monitored by an agency engineer (see 10 CSR 22-1.020(1)) do not need a construction permit but a set of plans shall be filed with the chief engineer prior to the initiation of any construction activity. These dams and reservoirs are required to have a registration or safety permit subsequent to construction.

(6) Industrial water retention dams (see 10 CSR 22-1.020(27)) and reservoirs regulated by another state agency or federal agency are exempted from all permit requirements. For the exemption to apply, the industrial water retention dam and reservoir must be subject to safety inspections by the other state agency or federal agency and standards used must be at least as stringent as those required by the law. In addition, the owner must notify the council that another agency is regulating his/her dam and reservoir and explain the basis for the exemption to apply.

AUTHORITY: sections 236.400, 236.415, 236.435, 236.440 and 236.465, RSMo 1986 and 236.405, RSMo Supp. 1993. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed Sept. 1, 1993, effective May 9, 1994.*

**Original authority: 236.400, 236.415, 236.435, 236.440 and 236.465, RSMo 1979 and 236.405, RSMo 1979, amended 1993.*

10 CSR 22-2.020 Types of Permits

PURPOSE: This rule describes the three types of permits and their uses that the Dam and Reservoir Safety Council will issue.

(1) There are three (3) types of permits—registration permits, construction permits and safety permits and each one is intended to regulate a separate and distinct type of activity. A dam and reservoir will have only one (1) type of permit in effect at any given time although they may have more than one (1) type of permit during their existence.

(2) Registration permits (see 10 CSR 22-1.020(44)) apply to and are required for the continued operation of a dam and reservoir that was in existence or in the process of being constructed on the effective date of this section, August 13, 1981. A registration permit also applies to and is required for structures which become subject to the provisions of the dam and reservoir safety law that were in existence prior to the date that they became subject to the law. Registration permits may be issued for a time period up to five (5) years. The owner of a dam and reservoir on the effective date of the law shall obtain his/her first registration permit in accordance with the height of his/her dam. For dam heights of thirty-five feet (35') to less than fifty feet (50'), fifty feet to seventy feet (50'–70') and over seventy feet (70+'), the maximum time to obtain the first registration permit is respectively within nine (9) years, four (4) years and two (2) years from the effective date of this section, August 13, 1981.

(3) Construction permits (see 10 CSR 22-1.020(8)) apply to the construction of a new dam and reservoir, the alteration, enlargement, reduction, repair or removal of a new or existing dam, reservoir or appurtenances. New dams are dams for which construction commences after the effective date of this section, August 13, 1981. For dams which were under construction on August 13, 1981, construction must be completed by August 13, 1987 or the owner will be required to obtain a construction permit. If completed prior to August 13, 1987, the owner will be required to obtain a registration permit as outlined in 10 CSR 22-2.020(2). A construction permit may be issued for any reasonable length time period required to complete construction and it may contain appropriate restrictions placed on the owner for construction and operation of the dam and reservoir during that period. At the conclusion of construction, a safety or registration permit shall be obtained by the owner.

(4) Safety permits (see 10 CSR 22-1.020(48)) apply to the operation of a dam and reservoir constructed pursuant to a construction permit. The safety permit is not a guarantee of the dam and reservoir's safety and does not alter the owner's liability; it is simply an operating permit. If a dam and reservoir were not subject to the provisions of the law when they were constructed but subsequently become subject to the provisions of the law, the owner shall obtain a registration permit, not a safety permit. Safety permits may be issued for a time period up to five (5) years, and they may contain appropriate conditions for the operation and safety of the dam and reservoir.

AUTHORITY: sections 236.400, 236.415, 236.435, 236.440 and 236.465, RSMo 1986 and 236.405, RSMo Supp. 1993. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed May 15, 1987, effective Sept. 15, 1987.*

**Original authority: 236.400, 236.415, 236.435, 236.440 and 236.465, RSMo 1979 and 236.405, RSMo 1979, amended 1993.*

10 CSR 22-2.030 Types of Dams and Reservoirs

PURPOSE: This rule describes the two fundamentally different types of dams and reservoirs that will be required to obtain permits from the Dam and Reservoir Safety Council.

(1) There are two (2) types of dams and reservoirs, conventional dams and reservoirs and industrial water retention dams and reservoirs. The two (2) types of dams and reservoirs are distinguished on the basis of their reservoir contents and the length of the time period during which active dam building occurs.

(2) Conventional dams and reservoirs (see 10 CSR 22-1.020(9)) are dams and reservoirs used for purposes other than tailings, slime, settling or other similar industrial water retention purposes. A conventional dam is constructed in one (1) relatively continuous operation over a short time span (compared to the design life of the reservoir). Filling and use of the reservoir occurs after construction is completed.

(3) Industrial water retention dams and reservoirs (see 10 CSR 22-1.020(27)) are dams and reservoirs used for the purpose of storing solids and the water associated with the particular industrial process such as tailings, slime and other similar industrial materials. An industrial water retention dam may be constructed in phases and steps or continuously, over a long period of time (compared to the design life of the reservoir). Filling and use of the reservoir may occur during most phases of construction. An industrial water retention dam and reservoir in existence or under construction on the effective date of 10 CSR 22-2.020(2), August 13, 1981, shall obtain a registration permit which may include approval to make enlargements. The owner of any such dam and reservoir shall apply for and obtain new construction and/or registration permits for any modifications to that dam and reservoir other than enlargements covered by an existing permit. A construction permit is required and shall be obtained by the owner, for the initial construction phase of any new industrial water retention dam and reservoir built after the effective date of 10 CSR 22-2.020(3), August 13, 1981. Upon completion of the initial construction phase, the owner shall apply for a safety permit for the operation and enlargement of the new dam and reservoir.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, 236.435, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.405, RSMo (1979), amended 1993 and 236.415, 236.435, 236.440 and 236.465, RSMo (1979).*

10 CSR 22-2.040 Classes of Downstream Environment

PURPOSE: This rule describes the three environmental classes for the downstream environmental zone that will be used by the Dam and Reservoir Safety Council when considering permits.

(1) The downstream environment zone is the area downstream from a dam that would be affected by inundation in the event the dam failed. Inundation is defined as water, two feet (2') or more deep over the general level of the submerged ground affected outside the stream channel. Based on the content of the downstream environment zone, three (3) environmental classes are defined. They are: class I, which contains ten (10) or more permanent dwellings or any public building; class II, which contains one to nine (1–9) permanent dwellings, or one (1) or more campgrounds with permanent water, sewer and electrical services or one (1) or more industrial buildings; and class III, which is everything else.

(2) Spillway design standards are based on the environmental class of the downstream environment zone of a dam and reservoir. The standards become more stringent for lower environmental class numbers. If conditions change in the downstream environment zone and it becomes necessary to change the environmental class of the dam and reservoir, the owner must then meet the standards and criteria for the new environmental class of the dam and reservoir. A dam and reservoir may be in only one (1) environmental class at a given time.

(3) Inundation, the downstream environmental zone and the associated environmental class are analyzed, assuming the dam fails with the reservoir at the emergency spillway crest elevation or the dam crest elevation in the absence of an emergency spillway. If the spillway standards for class I are used, the failure analysis does not have to be performed. If a failure analysis is made, the contents of the downstream environment zone used to determine the environmental class are only the features that would be inundated by the flooding resulting from the dam failure.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, 236.435, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.405, RSMo 1979, amended 1993 and 236.415, 236.435, 236.440 and 236.465, RSMo 1979.*

10 CSR 22-2.050 Issuing First Permit

PURPOSE: This rule describes the procedure for issuing the first permit to a dam and reservoir owner for a particular dam and reservoir.

(1) A permit will be issued or a letter will be sent to the owner with comments within forty-five (45) days after the receipt of a properly prepared application or after the completion of any hearings or record period conducted by the council in connection with the application, whichever is later. The council, upon hearing the recommendations of the chief engineer, shall approve or deny the permit application.

(2) A permit will be issued if a complete and proper application has been submitted and the dam and reservoir comply with the law.

(A) A registration permit may be denied if it is determined that the owner has not complied with the experienced professional engineer's or agency engineer's inspection recommendations.

(B) A construction permit may be denied if there is insufficient information to determine that the proposed construction, alteration, enlargement, reduction or removal of a dam or reservoir would not endanger public safety, life or property or otherwise would comply with the law.

(C) A safety permit may be denied if it is determined that there are violations of the construction permit or the law.

(D) If revisions have been made which vary substantially from the provisions of the construction permit, the owner must show that the revisions do not endanger public safety, life or property before a safety permit will be issued.

(3) Conditions contained in a construction permit shall include that the construction work must be under the responsible charge of an experienced professional engineer and the records be kept and made available as

required by the chief engineer including, without limitation, for the foundation excavation and inspection and placement of backfill in the core trench. It is not necessary for the engineer in responsible charge to be on-site continuously. During construction, the council or its delegate, the chief engineer, may make periodic site inspections the purpose of inspecting and securing conformity of construction with the approved plans and specifications and the owner shall permit, upon reasonable notice, the person entry upon its property to make such inspections. The owner may be required to perform, at its own expense, reasonable work or tests as are necessary to provide sufficient information to enable the council to determine that there is conformity. Usually, testing will be limited to verification of embankment compaction, concrete strengths and other similar requirements. It is expected that the tests will be required where the owner's inspection records are lacking.

(4) Any significant modifications from a construction permit or approved plans makes the permit void and requires the owner to obtain a new permit. Significant modification to the plans and specifications must be prepared by an experienced professional engineer. The council or its delegate will follow the same evaluation procedures for the modifications as used with issuance of the original construction permit. Special attention will be given to these modification requests to provide a quick decision.

(5) The owner of a dam and reservoir that is removed under a construction permit must notify the council or its delegate when this work is completed and in conformity with the provisions of the construction permit. The council or its delegate will then issue a final approval to relieve the owner of the requirement to have a permit upon a showing that the requirements of the law for removal have been satisfied.

(6) Approval by the council for a construction permit becomes invalid within one (1) year, unless work on the construction has begun within that period, except that the owner may be excused from beginning work for a period of time that the work is prevented by flood, shortage of materials or regulation of government which cannot be met for reasons over which the owner has no control or other causes beyond the owner's control. The same applies to construction of approved modifications contained in the conditions of a registration or safety permit for industrial water retention dams unless the conditions specify a different time schedule.

AUTHORITY: sections 236.400, 236.415, 236.435, 236.440 and 236.465, RSMo 1986 and 236.405, RSMo Supp. 1993. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.400, 236.415, 236.435, 236.440 and 236.465, RSMo 1979 and 236.405, RSMo 1979, amended 1993.*

10 CSR 22-2.060 Issuing Permit Renewals

PURPOSE: This rule describes the procedure for renewing a permit.

(1) The owner of a permitted dam and reservoir must apply for the renewal of the permit not less than sixty (60) days prior to expiration of that permit. Before any permit may be renewed, the chief engineer must determine that the dam and reservoir are essentially as described in the latest permit and approved plans; they satisfy the law; and that no inspection conducted in connection with the permit renewal reveals any defect which would threaten public safety, life or property. The council, or its delegate will issue another permit within forty-five (45) days of the receipt of a complete and proper application unless it is determined that the dam and reservoir are not as described in the latest permit and approved plans; not properly maintained; do not satisfy the law; or that the defects are not corrected.

(2) The council may require the owner to furnish a certification by an experienced professional engineer or an agency engineer that the dam and reservoir are as described in the latest permit and approved plans; are properly maintained; satisfy the law; and have all defects corrected.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.405, RSMo 1979, amended 1993 and 236.415, 236.440 and 236.465, RSMo 1979.*

10 CSR 22-2.070 Modifications not Requiring Permit Changes
(Rescinded January 1, 1985)

AUTHORITY: sections 236.405, 236.415, 236.435, 236.440, and 236.465, RSMo Supp. 1980. Original rule filed April 14, 1981, effective Aug. 13, 1981. Rescinded: Filed June 14, 1984, effective Jan. 1, 1985.

10 CSR 22-2.080 Revoking Permit

PURPOSE: This rule describes the reasons for revoking a permit.

(1) Approval of the council or its delegate, the chief engineer, shall be obtained for modifications that substantially alter or adversely affect the safety or stability of the dam or reservoir. Modifications, without the approval of the council or its delegate, the chief engineer, are cause for suspension or revocation of any permit. If the chief engineer finds that the condition of the dam and reservoir has deteriorated substantially from those conditions present when the permit was issued, or that has defects which adversely affect the safety or stability of the dam and reservoir or threatens public safety, life or property, s/he shall revoke the permit. If a permit is suspended or revoked, the dam owner will be in violation of the law and may be subject to prosecution for a misdemeanor.

(2) If the chief engineer determines that a dam or reservoir constitutes a threat to public safety, life or property, s/he may order its removal or take any other actions necessary to reduce or eliminate the threat. Failure of a dam owner to alter or remove his/her dam and reservoir as directed, when it is found to be a threat to public safety, life or property, will result in revocation of the permit and, if necessary, removal of the dam or any other action necessary to reduce or eliminate the threat to public safety, life or property by the state at the owner's expense.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, 236.445, 236.495 and 236.500, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.405, RSMo 1979, amended 1993 and 236.415, 236.445, 236.495 and 236.500, RSMo 1979.*

10 CSR 22-2.090 Transferring Permit

PURPOSE: This rule describes the procedure for transferring a permit when ownership changes.

(1) Permits issued pursuant to 10 CSR 22-2.050 and 10 CSR 22-2.060 are transferable only as provided in section 236.460, RSMo.

If ownership or other transfer of interest in the dam and reservoir changes, the former owner must notify the chief engineer of the sale or transfer and the permit will be transferred to the new owner after determination that the transfer will not endanger the public safety, life, property, the dam or reservoir. The permit holder of record will be held responsible for maintaining compliance with these rules and standards. If the former owner does not have the permit transferred, the new owner may submit the appropriate application and documents necessary to obtain a new permit. The new owner, in this case, must also show proof of ownership. The old owner's responsibilities of ownership under the law will not be extinguished until the permit is transferred to an eligible owner. Nothing in these regulations shall be construed to eliminate the liability of the previous owner for damages or injuries caused by a dam failure, nor a new operator who has not obtained a permit nor had an existing permit transferred to his/her name.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, and 236.460, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective, Jan. 1, 1985.*

**Original authority: 236.405, RSMo 1979, amended 1993 and 236.415 and 236.460, RSMo 1979.*

10 CSR 22-2.100 Appeal of Action on Permits

PURPOSE: This rule describes the procedure for appealing the results of any action taken with regard to a permit.

(1) Permits revoked or denied are subject to council appeal. All parties shall be afforded an opportunity for hearing before the council for review of denial or revocation decisions, if request is made within thirty (30) days after notice is served personally or by certified or registered mail upon the parties or their agents. Except for emergency action, further legal action shall not be taken until after the hearing and council decision.

(2) The record of hearing shall include all written testimony, data, records, etc., as well as all oral proceedings recorded stenographically or by other means that will preserve the testimony. Rules of discovery, evidence and privilege as applied in civil cases in the circuit courts shall be followed.

(3) A final decision will be in writing, and the party or its agents will be notified personally or by registered or certified mail of the final decision. A copy of any opinion in support of this decision will be furnished upon request. Decisions are subject to judicial review pursuant to provisions of section 236.480, RSMo.

AUTHORITY: sections 236.405, RSMo Supp. 1993 and 236.415, 236.425, 236.440, 236.445, 236.470 and 236.480, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.405, RSMo 1979 amended 1993 and 236.415, 236.425, 236.440, 236.445, 236.470 and 236.480, RSMo 1979.*

Rules of
Department of Natural Resources
Division 22—Dam and Reservoir Safety Council
Chapter 3—Permit Requirements

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Title 10—DEPARTMENT OF NATURAL RESOURCES
Division 22—Dam and Reservoir Safety Council
Chapter 3—Permit Requirements

10 CSR 22-3.010 General Information

PURPOSE: The purpose of this rule is to provide general information about permit requirements.

(1) Requirements for existing or proposed dams and reservoirs must allow for variations in conditions and materials from site-to-site. Therefore, this rule and 10 CSR 22-3.020—10 CSR 22-3.050 describe the minimum general requirements which are consistent with current engineering, geologic, construction, operation and maintenance practices, necessary to obtain permits from the Dam and Reservoir Safety Council.

(2) These rules are not intended to define the only requirements for a dam and reservoir to comply with the law or sound engineering, geologic and construction practices, to be used in detailed site investigation or in the specific design and construction of individual dams. The detailed and specific information that outlines current and prudent engineering, geologic and construction practices is available in technical literature. Determinations by the Dam and Reservoir Safety Council, after hearing the recommendations of the chief engineer of the acceptability of a design and adequacy of plans, specifications and construction must be made, by necessity, on a case-by-case basis. Therefore, it is recommended that applicants unfamiliar with the way these rules are applied contact the council or the chief engineer prior to commencing extensive work or plan development.

(3) Adherence to the law does not guarantee the safety of any dam or reservoir or relieve the owner of any liability in the event of dam failure.

(4) A permit application form along with a copy of the laws, rules, standards and guidelines relating to dam and reservoir safety can be obtained free from the Department of Natural Resources, Division of Geology and Land Survey, Dam Safety Program, P.O. Box 250, Rolla, MO 65401. Persons seeking this and/or other information on dams in Missouri should address their inquiry to the chief engineer.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.435, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981.*

**Original authority: 246.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.435, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-3.020 General Requirements

PURPOSE: The purpose of this rule is to itemize the basic requirements and standards that apply to all permits.

(1) The permit application must contain information required by the council and the chief engineer including, but not limited to, the following information: type of permit being applied for; name of owners; mailing address of owners; telephone number(s) of owners; name of dam; name of reservoir; coordinate location of the dam centerline at the maximum section; purpose or use of dam and reservoir; name, address and telephone number of the experienced professional engineer or agency engineer who has provided or will provide required technical assistance; and the downstream environment zone environmental class for the dam and reservoir. The owners must complete all applicable investigations required in 10 CSR 22-3.0202–10 CSR 22-3.050 before filing a permit application. All permit applications must be filed with the chief engineer at the address listed in 10 CSR 22-3.010(4).

(2) The owner must provide a determination of an environmental class for each dam and reservoir. The method, data and assumptions used by the owner to determine environmental class shall conform to practices reputable and in current use in the engineering, geologic and construction professions or the chief engineer may reject the owner's classification. If an owner chooses not to have this done by an experienced professional engineer or an agency engineer, the chief engineer will assign the dam and reservoir to environmental class I or s/he may assign the dam and reservoir to another environmental class if s/he has justification to do so.

(3) The anticipated consequences of a dam failure with respect to public safety, life and property damage are important considerations in establishing acceptable methods for specific investigations and sites. Methods used in exploration design, construction and maintenance must be in accordance with good engineering practices reputable and in current use in the engineering, geologic and construction professions.

(4) When the owner is applying for a construction permit, the required design factors of safety for slope stability for earth and rock conventional dams which are given in Table 1 shall be met. The required design factors of safety for concrete conventional dams are given in Table 2. The required design factors of safety for slope stability for industrial water retention dams are given in Table 3. Owners shall meet these requirements in the design of new dams prior to the issuance of the permit. Owners shall also meet these requirements when substantial changes are proposed to the height or slope of an existing conventional dam or structure prior to the issuance of the construction permit (see the following tables).

(5) For new dams constructed wholly or partially of cohesionless materials (such as sands and silts) or having a foundation of cohesionless materials, earthquake loading may result in the build-up of pore water pressures and a loss of strength. Engineers shall take this pore pressure increase and loss of strength into account when performing their stability analysis, but the degree to which liquefaction may affect the factor of safety for slope stability shall be left up to the engineer's best judgment. Bedrock accelerations and earthquake intensities are listed in Table 4.

(6) New dams constructed wholly of cohesive materials (such as clays) and having a foundation of cohesive materials or rock, can be expected to withstand significant earthquake shaking if it can be shown that other required design factors of safety for slope stability are met. Therefore, only new dams located in Bollinger, Butler, Cape Girardeau, Dunklin, Mississippi, New Madrid, Pemiscot, Ripley, Scott, Stoddard and Wayne Counties must meet the requirements for slope stability during earthquake loading while dams located in other counties do not unless 10 CSR 22-3.030(5) applies to them. Bedrock accelerations and earthquake intensities are listed in Table 4.

Table 1—Required Design Factors of Safety for Slope Stability Earth and Rock Conventional Dams

Loading Condition	Factor of Safety
End of construction, full reservoir*	1.4
Steady seepage, full reservoir*	1.5
Steady seepage, maximum reservoir**	1.3
Sudden draw down, from full to empty reservoir (if applicable)	1.2
Earthquake***, steady seepage, full reservoir*	1.0

*Full reservoir means water level is at the water storage elevation.
**Maximum reservoir means water level is at maximum water level attained during the spillway design flood or at the dam crest elevation, whichever is lower.
***Earthquake loading will vary according to dam location in relation to seismic source zones and downstream environmental zones. (See Table 4).

Table 2—Required Design Factors of Safety Concrete Conventional Dams

Failure Mode	Loading Condition	Factor of Safety
Overturning	full reservoir*	1.5
	maximum reservoir**	1.3
Sliding	full reservoir*	1.5
	maximum reservoir**	1.3
Structural integrity	full reservoir*	1.5
	maximum reservoir**	1.3
Earthquake*** any mode	full or maximum reservoir* & **	1.0

*Full reservoir means water level is at the water storage elevation.
**Maximum reservoir means water level is at maximum level attained during the spillway design flood.
***Earthquake loading will vary according to dam location in relation to seismic source zones and downstream environmental zones. (See Table 4).

Table 3—Required Design Factors of Safety for Slope Stability Industrial Water Retention Dams

Loading Condition	Factor of Safety
Starter dam, end of construction, full reservoir*	1.4
Any other stage of construction, full reservoir*, steady seepage	1.3
Any other stage of construction, maximum reservoir*, steady seepage	1.0
Completed dam, full reservoir*, steady seepage	1.5
Completed dam, maximum reservoir**, steady seepage	1.3
Earthquake***, steady seepage, full reservoir*	1.0

*Full reservoir means water level is at the water storage elevation.
**Maximum reservoir means water level is at the maximum level attained during the spillway design flood or at the dam crest elevation, whichever is lower.

***Earthquake loading will vary according to dam location in relation to seismic source zones and downstream environmental zones. (See Table 4).

(7) The required spillway design flood, which shall allow for flood storage in the reservoir, is to be derived by using the precipitation values given in Table 5 and shall apply to both new and existing dams.

Table 4—Required Design Acceleration For Earthquake Design

Dam Type	Stage of Construction	Special Descriptions	Environmental Class I	Environmental Class II	Environmental Class III
Conventional or Industrial	Completed	New dams less than 50 feet in height	.75PMA*	.5PMA*	.25PMA*
		New dams greater than 50 feet in height**	.75PMA*	.5PMA*	.4PMA*
Industrial	Starter dam	New dams**	.5PMA*	.2PMA*	.1PMA*
	dam is completed	After starter dam is finished and before final New dams**	.75PMA*	.5PMA*	.2PMA*

Zone	PMA*	Intensity**
A	0.31 g	IX—X
B	0.28 g	IX
C	0.26 g	VIII—IX
D	0.23 g	VIII
E	0.20 g	VII—VIII
F	0.17 g	VII

ZONE A	ZONE B	ZONE C	ZONE D	ZONE E	ZONE E (cont.)	ZONE F
Dunklin	Bollinger	Carter	Crawford	Audrain	Lewis	Adair
Mississippi	Butler	Howell	Dent	Barry	Lincoln	Andrew
New Madrid	Cape Girardeau	Iron	Douglas	Barton	Linn	Atchison
Pemiscot	Ripley	Madison	Franklin	Bates	Livingston	Buchanan
	Scott	Oregon	Jefferson	Benton	McDonald	Clay
	Stoddard	Perry	Ozark	Boone	Macon	Clinton
	Wayne	Reynolds	Phelps	Caldwell	Maries	Davis
		St. Francois	Pulaski	Callaway	Marion	Dekalb
		Ste. Genevieve	St. Louis	Camden	Miller	Gentry
		Shannon	St. Louis City	Carroll	Moniteau	Grundy
			Taney	Cass	Monroe	Harrison
			Texas	Cedar	Montgomery	Holt
			Washington	Chariton	Morgan	Mercer
			Wright	Christian	Newton	Nodaway
				Clark	Osage	Platte
				Cole	Pettis	Putnam
				Cooper	Pike	Schuyler
				Dade	Polk	Sullivan
				Dallas	Ralls	Worth
				Gasconade	Randolph	
				Greene	Ray	
				Henry	St. Charles	
				Hickory	St. Clair	
				Howard	Saline	
				Jackson	Scotland	
				Jasper	Shelby	
				Johnson	Stone	
				Knox	Vernon	
				Laclede	Warren	
				Lafayette	Webster	
				Lawrence		

* PMA is Probable Maximum Acceleration of bedrock which is determined as a fraction of the acceleration of gravity (g = 32.2 fps2) for the six zones in Missouri (see 10 CSR 22-1.020(41)).

** See 10 CSR 22-2.020(3) for clarification.

*** Modified Mercalli Intensity.

Table 5—Required Spillway Design Flood Precipitation Values

			Environmental Class		
Dam Type	**Stage of Construction**	**Special Descriptions**	**I**	**II**	**III**
Conventional or Industrial	Completed	Any existing dam**	.75PMP*	.5PMP*	100 Yr.****
	New dam less than 50 feet in height***		.75PMP*	.5PMP*	100 Yr.****
	New dam greater than 50 feet in height		.75PMP*	.5PMP*	100 Yr.*****
Industrial	Starter dam	Any	.5PMP*	.2PMP*	.1PMP*
	After starter dam is finished and before final dam is completed	Any	.75PMP*	.5PMP*	.2PMP*

*PMP is Probable Maximum Precipitation.
**Existing dam means a dam which was completed by August 13, 1981 or which was started prior to August 13, 1981 and completed by August 13, 1987.
***See 10 CSR 22-2.020(3) for clarification.
****100 Yr. is the 100 year frequency rainfall event.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.435, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985. Amended: Filed Aug. 15, 1988, effective Jan. 1, 1989. Amended: Filed May 15, 1990, effective Nov. 30, 1990.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415 RSMo 1979, amended 1995; 236.435, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-3.030 Registration Permit Requirements

PURPOSE: The purpose of this rule is to itemize the requirements for a registration permit.

(1) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020(1), (2), (3) and (7), the registration permit application for a conventional dam and reservoir must include certification by an experienced professional engineer or an agency engineer that the dam and reservoir have been inspected in accordance with the law and that the owner has compiled engineer's recommendations to correct the observed defects and an inspection report, as required by the law. The engineer must further show that the spillway can safely pass the spillway design flood derived from Table 5 and submit a report describing the correction of all observed defects and the description of an operation and maintenance program to be followed while the registration permit is in effect.

(A) The inspection of a dam and reservoir for a registration permit is intended to detect observable defects. The procedure to determine observable defects normally will be a surface examination by an experienced professional engineer or an agency engineer. The inspection must include all surface examinations necessary to determine if observable defects exist that affect the stability of the dam and reservoir or the adequacy of the spillway. Judgment of the structural stability and an evaluation of the spillway capacity must be made. Judgment shall be based upon the engineer's experience, training and knowledge of similar dams and in accordance with practices reputable and in current use in the engineering, geologic and construction professions.

1. Observed defects which may require correction, evaluated on the basis of current engineering, geologic and construction practices, include but are not limited to: slides; slopes as steep as or steeper than those on similar types of dams and constructed of similar materials which have experienced slope stability problems; piping of fines; seepage that exits in an uncontrolled fashion on the downstream slope of or from the downstream foundation of the dam; unusual zones of softness and irregular settlement; erosion on the upstream or downstream slope of the dam; spillways that are calculated to be inadequate for the design flood; spillways that are eroded or otherwise in poor condition and cracks in the embankment or structure.

2. Observed defects that are in an advanced state of deterioration must be immediately reported by the inspecting engineer to the owner and to the chief engineer.

(B) Proper maintenance and operation of a dam and reservoir are critical to the continuing safety of a dam and reservoir and to public safety, life and property. A maintenance program shall be required and shall include the following items: erosion control on the embankment; monitoring emergency spillway flow rates; vegetation control; spillway maintenance; emergency action plans; maintenance and monitoring of seepage observation devices, if any; and maintenance and monitoring of instruments used, if any, to observe the stability of the dam.

(C) Visits for the purpose of observation of maintenance and operation may be made by the council, the chief engineer or a member of the chief engineer's staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, no notice shall be required and inspection may be at any time. Owners shall permit entry to its property for persons to perform the inspections.

(D) The application need not state, nor is it necessary to show, that the dam is a safe dam. The intent of the registration permit is to show that the dam is performing adequately and that there are no observable indications that the dam is unsafe.

(2) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020(1), (2), (3) and (7), the registration permit application for an industrial water retention dam and reservoir shall include certification by an experienced professional engineer or an agency engineer that the dam and reservoir have been inspected in accordance with the law and that the owner has complied with the engineer's recommendations to correct observed defects and an inspection report, as required by the law. The engineer must further show that the spillway can safely pass the spillway design flood derived from Table 5 and submit a report describing the correction of any observed defects, the operation and maintenance program to be made a part of the registration permit and the phased, stepped and/or continuous construction of the dam.

(A) The inspection of an industrial water retention dam and reservoir for a registration permit is intended to detect observable defects. The procedure to determine observable defects normally will be a surface examination by an experienced professional engineer or an agency engineer. The inspection must include all surface examinations necessary to determine if observable defects exist that affect the stability of the dam and reservoir or the adequacy of the spillway. Judgment of the structural stability and an evaluation of the spillway capacity must be made. Judgment shall be based upon the engineer's experience, training and knowledge of similar dams and in accordance with practices reputable and in current use in the engineering, geologic and construction professions.

1. Observed defects which may require correction, evaluated on the basis of current engineering, geologic and construction practices, include but are not limited to slides; slopes as steep as or steeper than those on similar types of dams and constructed of similar materials which have experienced slope stability problems; piping of fines; seepage that exits in an uncontrolled fashion on the downstream slope of or from the downstream foundation of the dam; unusual zones of softness and irregular settlement; erosion on upstream or downstream slope of the dam; spillways that are calculated to be inadequate for the design flood; spillways that are eroded or otherwise in poor condition and cracks in the embankment or structure.

2. Observed defects that are in an advanced state of deterioration must be immediately reported by the inspecting engineer to the owner and to the chief engineer.

(B) Proper maintenance and operation of a dam and reservoir are critical to the continuing safety of a dam and reservoir and the protection of public safety, life and property. A maintenance program shall be required and shall include the following items: erosion control on the embankment; monitoring of storm runoff; vegetation control; spillway maintenance; emergency action plans; maintenance and monitoring of seepage observation devices, if any; and maintenance and monitoring of instruments used, if any, to observe the stability of the dam.

(C) The council or chief engineer may require the owner to submit a report describing the phased, stepped and/or continuous construction of an industrial water retention dam and reservoir, containing information on

the materials used, method of transport and placement of materials, the sequence and placement location of materials, spillway changes to be made, the anticipated final dimensions and configuration of the dam and the name, address and telephone number of the person(s) in responsible charge of this work.

(D) Visits for the purpose of inspecting during construction or enlargement or observation of maintenance and operation may be made by the council, the chief engineer or a member of the chief engineer's staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, no such notice shall be required and inspection may be made at any time. Owners shall permit entry to its property for persons to perform inspection.

(E) It shall not be necessary for the owner to retain an experienced professional engineer or an agency engineer continuously during the entire permit period unless there is modification(s) in the construction method described in the permit application. However, personnel with adequate supervision and training in methods of safe construction, maintenance and operation of dams must be provided to insure that the construction maintenance and operation of the dam and reservoir are carried out as described.

(F) The registration permit will be the only permit required for an industrial water retention dam and reservoir that was in existence prior to the effective date listed in 10 CSR 22-2.020(2) unless it is to be reduced or removed. If the dam or reservoir is to be reduced or removed, a construction permit will be required. Other changes will require the owner to obtain a new registration permit.

(G) The applicant need not state, nor is it necessary to show, that the dam is a safe dam. The intent of the registration permit is to show that the dam is performing adequately and that there are no readily observable indications that the dam is unsafe and that phased, stepped and/or continuous construction of the dam will meet the requirements of the law.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.420, 236.425, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.420, RSMo 1979; 236.425, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-3.040 Construction Permit Requirements

PURPOSE: The purpose of this rule is to itemize the requirements for a construction permit.

(1) In addition to the basic requirements for all permits listed in 10 CSR 22-3.030, the construction permit application for a conventional dam and reservoir shall be prepared under the direction of and certified by an experienced professional engineer and shall be in accordance with practices reputable and appropriate in the engineering, geologic and construction professions.

(A) The following requirements shall apply to and the following information shall be provided by the owner:

1. Up-to-date topographic map(s) showing the location of the proposed or existing dam, the upstream watershed, the reservoir and the downstream environment zone. The topographic map(s) of the project area must be at a scale appropriate to the size of the project area. An up-to-date United States Geological Survey topographic map is considered a minimum;

2. Exploration records and results including the location of all exploration, especially in the area of the core trench, the method(s) used to explore the site, a record of what was found, the method(s) used to obtain samples and the number of samples taken;

3. Testing records and results including information on the care and treatment of samples, types of tests performed on samples or in situ, reference(s) to or the procedures used in testing and the test results. Physical and mechanical properties of foundation and construction materials must include the information source for these values especially if they are not the results of testing;

4. The geotechnical design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and the applicability verified. This shall include all assumptions made. The geotechnical procedure(s) or design results shall include the minimum computed factors of safety and they must meet or exceed the required design factors of safety (see 10 CSR 22-3.020(4)). The geotechnical design information shall be presented for the foundation, core trench and dam embankment. Earthquake loading must be analyzed as outlined in 10 CSR 22-3.020(5) and (6);

5. The structural design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. Design results for concreted dams and concrete structures appurtenant to embankment dams shall provide for and show an adequate factor of safety for normal and maximum loading conditions of compression, tension, shear, torsion, buckling, sliding and overturning;

6. Hydrologic information used to evaluate the watershed, reservoir, spillway and downstream environment zone including the watershed area, rainfall rate and duration, antecedent moisture conditions, time of concentration, area capacity curves, description of spillway elevation(s), type(s), dimensions, locations, cross section and profiles, dam crest elevation and the downstream valley cross sections;

7. The hydrologic/hydraulic design procedure(s) or method(s) used shall be identified and referenced or described so that they may be reviewed and their applicability verified. This shall include all assumptions made. The hydrologic/hydraulic procedure(s) or design results shall include the reservoir inflow hydrograph, the reservoir outflow hydrograph, the spillway discharge capacity, the freeboard at the maximum water storage elevation and the environmental class of the dam. The dam shall be capable of safely containing or discharging the required design flood (see 10 CSR 22-3.020(5));

8. Location and design of diversion channels or other structures to control stream flow during or after construction shall be provided if failure of these channels or other structures would affect hydrologic conditions of the dam. Stream diversion systems used during construction shall be designed to provide protection to the dam and the safety of the public;

9. Construction control and inspection procedures shall be used during the construction of a new dam and reservoir or modification of an existing dam and reservoir. Construction control and inspection procedures should include compaction testing and density testing;

10. Procedures shall be used for recordkeeping and monitoring throughout the construction or modification process to provide information about any construction progress and conditions that may cause difficulties during construction;

11. The location of and protective measures used in conjunction with all drain lines, sewer lines, utilities or other structures that pass through or under the dam;

12. Topographic surveys showing the location of baselines, centerlines and other horizontal and vertical control points sufficiently accurate to locate the proposed construction and to define the volume of storage in the reservoir;

13. Two (2) sets of plans and specifications including—

A. Graphic scales shall be provided for all scaled drawings;

B. The title, which shall be identical on the plans and the specifications, shall include: the name of the dam; the name of the owner; whether the work shows an existing dam, a proposed dam or an enlargement, repair or alteration of the dam or reservoir; the county(ies) the dam and reservoir are in; the location of the dam by quarter section, section, township and range or by geodetic coordinates; and each sheet shall have in an appropriate title block the name of the dam as well as the sheet number in relation to the total, for example, sheet one (1) of twelve (12); and

C. Certifications by the experienced professional engineer and the owner shall be placed near the lower right-hand corner of the title sheet (first sheet) of the drawings. The certifications shall be similar to those presented in figures 1 and 2 (see figures 1 and 2); and

Figure 1

Certification by Experienced Professional Engineer

I hereby certify that these plans for the (insert the correct word or words choosing

from: existing; construction of the; repair of the; enlargement of the; or alteration of the

_____ Dam were prepared by me (or under my
Name of Dam

direct supervision) for the owners thereof.

_____
Firm Name

_____
Registered Engineer

(Seal)

Figure 2

Certification by Owner

I,_____, owner, whose Post Office Address is
Name of Owner

_____ , Zip _____ , do
Owner's Address

hereby accept and approve these plans.

_____
Owner

14. If a construction permit is requested to convert a dam to a retaining or retarding structure, the procedure to be followed in making the conversion shall be described by the owner; and

15. The procedures set up for regular inspection by the owner. The owner shall develop an emergency action plan, inspect his/her dam regularly and as necessary to protect public safety, life and property. A list of items to be inspected, a time schedule for these inspections and a form for reporting the results shall be established.

(B) The council or chief engineer may require the following action and information from the owner:

1. Procedures set up to provide regular maintenance and minor repairs to the dam and reservoir after construction and to continue or start recordkeeping and monitoring work so that the dam and reservoir are maintained in a safe condition and a complete history of its performance is available;

2. Location and types of instrumentation, drainage and/or seepage control facilities. Monitoring equipment and drainage and seepage control facilities are recommended for all dams and reservoirs, however, depending on conditions, they may be mandatory items if necessary to accomplish the purposes of the law;

3. The downstream environment zone warning procedure to be used if dam failure is a threat. A downstream environment zone warning system is recommended for all dams and reservoirs, however, depending on conditions, it may be necessary to accomplish the purposes of the law. This would consist of the current name(s) of the dam and reservoir owners representative(s) responsible for giving notification of a threat of failure and the current phone numbers of appropriate local police and other persons having emergency assistance authority;

4. Upstream slope protection from wave action; and

5. Additional actions or information as required to protect public safety, life and property and to accomplish the purposes of the law.

(C) Visits for the purpose of inspecting during or after construction or observation of operation and maintenance may be made by the council, the chief engineer or a member of the chief engineer's staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, no notice shall be required and inspection may be made at any time. Owners shall permit entry to their property for persons to perform inspections.

(2) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020, the construction permit application for an industrial water retention dam and reservoir shall be prepared under the direction of and certified by an experienced professional engineer and shall be in accordance with practices reputable and appropriate in the engineering, geologic and construction professions.

(A) The engineer who plans and designs an industrial water retention dam and reservoir or its modification shall assess the sequence, timing, method of placement and stability control program during construction from the beginning of the starter dam or modification through the life of the structure and after operation ceases or until the dam and reservoir no longer need a permit.

(B) Adequate records, as required by best practices in the geologic and engineering professions, shall be kept and made available to the council or chief engineer for the construction, maintenance and operation procedures. Adequate instrumentation and monitoring of seepage water shall be provided where necessary. Any significant settling or movement in the foundation of the dam should be measured if possible. Trained personnel and adequate supervision shall be provided to insure the construction and operation of the dam and reservoir are carried out to specifications.

(C) The following requirements shall apply to and the following information shall be provided by the owner:

1. A description of the system used to deposit tailings on the dam;

2. Up-to-date topographic map(s) showing the location of the proposed dam, the upstream watershed, the reservoir and the downstream environment zone. The topographic map(s) of the project area must be at a scale appropriate to the size of the project area. An up-to-date United States Geological Survey topographic map is considered minimum;

3. The location(s) of surface and underground mine workings if these workings would cause, would contribute to the cause or would be affected in the event of failure;

4. Exploration records and results including the location of all exploration, especially in the area of the core trench, the method(s) used to explore the site, a record of what was found, the method(s) used to obtain samples and the number of samples taken;

5. Testing records and results including information on the care and treatment of samples, types of tests performed on samples or in situ, reference(s) to or the procedures used in testing and the test results. Physical and mechanical properties of foundation and construction materials must include the information source for these values especially if they are not the results of testing;

6. The geotechnical design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. This shall include all assumptions made. The geotechnical procedure(s) or design results shall include the minimum computed factors of safety and they must meet or exceed the required design factors of safety (see 10 CSR 22-3.020(4)). The geotechnical design information shall be presented for the foundation core trench and dam embankment. Earthquake loading must be analyzed as outlined in 10 CSR 22-3.020(5) and (6).

7. Type and physical properties of the liquid and solid materials to be used in construction of the dam and contained in the reservoir;

8. The changes created in the downstream environment zone as the dam and reservoir become incrementally larger;

9. The embankment changes and new factors of safety for stability as the dam and reservoir become incrementally larger;

10. If a starter dam is used, whether it will be pervious or impervious;

11. The expected crest elevation, dam configuration, spillway elevation and the size and configuration of each successive stage of the dam shall be included;

12. Anticipated storage volume of solid or semisolid materials and of liquids at the completion of the dam;

13. The structural design procedure(s) or method(s) shall be identified and referenced or described so that they may be reviewed and their applicability verified. Design results for concrete dams and concrete structures appurtenant to embankment dams shall provide for and show an adequate factor of safety for normal and maximum loading conditions of compression, tension, shear, torsion, buckling, sliding and overturning;

14. Hydrologic information used to evaluate the watershed, reservoir, spillway and downstream environment zone including the watershed area, rainfall rate and duration, antecedent moisture conditions, time of concentration, area capacity curves, description of spillway elevation(s), type(s), dimensions, locations, cross sections and profiles, dam crest elevation and the downstream valley cross sections;

15. Hydrologic/hydraulic design procedure(s) or method(s) used shall be identified and referenced or described so that they may be reviewed and their applicability verified. This shall include all assumptions made. The

hydrologic/hydraulic procedure(s) or design results shall include the reservoir inflow hydrograph, the reservoir outflow hydrograph, the spillway discharge capacity, the freeboard at the maximum water storage elevation and the environmental class of the dam. The dam shall be capable of safely containing or discharging the required design flood (see 10 CSR 22-3.020(5));

16. The hydrologic changes, the spillway alterations proposed and the freeboard changes as the dam becomes incrementally larger;

17. Location and design of diversion channels or other structures to control stream flow during or after construction shall be provided if failure of these channels or other structures would affect the stability or hydrologic conditions of the dam. Stream diversion systems used during construction shall be designed to provide protection to the dam and to protect public safety, life and property;

18. Location and design of any diversion channels or other structures to control runoff or reclaimed water;

19. Construction control and inspection procedures shall be determined by the engineer and used during the construction of a new dam and reservoir or modification of an existing dam and reservoir. Construction control and inspection procedures shall include compaction testing and density testing and any other quality control measures used to insure compliance with the construction specifications;

20. Procedures shall be used for recordkeeping and monitoring throughout the construction, enlargement or modification process to provide information about any construction progress and conditions that may cause difficulties during construction;

21. The location of and protective measures used in conjunction with all drain lines, sewer lines, utilities or other structures that pass through or under the dam;

22. Topographic surveys showing the location of baselines, centerlines and other horizontal and vertical control points sufficiently accurate to locate the proposed construction and to define the volume of storage in the reservoir at each planned stage of construction;

23. Two (2) sets of plans and specifications including:

A. Graphic scales shall be provided for all scaled drawings;

B. The title, which shall be identical on the plans and the specifications, shall include: the name of the dam; the name of the owner; whether the work shows an existing dam, a proposed dam or an enlargement, repair or alteration of the dam and reservoir; the county(ies) the dam and reservoir are in; the location of the dam by quarter section, section, township and range or by geodetic coordinates; and each sheet shall have in an appropriate title block the name of the dam as well as the sheet number in relation to the total, for example, sheet one (1) of twelve (12); and

C. Certification by the experienced professional engineer and the owner shall be placed near the lower right-hand corner of the title sheet (first sheet) of the drawing. The certifications shall be as presented in figures 1 and 2 (see figures 1 and 2 preceding);

24. If a construction permit is requested to convert a dam to a retaining or retarding structure, the procedure to be followed in making the conversion shall be described by the owner; and

25. The procedure set up for regular inspection by the owner. The owner shall develop an emergency action plan, inspect his/her dam and reservoir regularly and as necessary to protect public safety, life and property. A list of items to be inspected, a time schedule for these inspections and a form for reporting the results shall be established by the council or chief engineer. Items that shall receive maintenance to and/or inspections on a daily basis during periods of active dam enlargement include: the spigots or cyclones; the decant lines; the position of the water pool in relation to the spillway, decant intake and crest of the tailings dam; drain lines checked for quantity of water and sediment; the embankment observed for visual defects such as slides or significant seepage changes; the spillway shall be checked to verify that it has not become blocked.

(D) The council or chief engineer may require the following action and information from the owner:

1. Procedures set up to provide regular maintenance and minor repairs to the dam and reservoir during construction and enlargement so that the dam and reservoir are maintained in a safe condition and a complete history of its performance is available;

2. Location and types of instrumentation, drainage and/or seepage control facilities. Monitoring equipment and drainage and seepage control facilities are recommended for all dams and reservoirs, however, depending on conditions they may be mandatory items if necessary to accomplish the purposes of the law; a list of items to be inspected, a time schedule for these inspections and a form for reporting the results shall be established by the council or chief engineer;

3. The downstream environment zone warning procedure to be used if dam failure is a threat. A downstream environment zone warning system is recommended for all dams and reservoirs, however, depending on conditions, it may be necessary to accomplish the purposes of the law. This would consist of the current name(s) of the dam and reservoir owners representative(s) responsible for giving notification of a threat of failure and the current phone numbers of appropriate local police and other persons having emergency assistance authority;

4. Upstream slope protection from wave action; and

5. Additional actions or information as required to protect public safety, life and property and to accomplish the purposes of the law.

(E) Visits for the purpose of inspecting during or after construction or observation of operation and maintenance may be made by the council, the chief engineer or member of the chief engineer's staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, no notice shall be required and inspection may be made at any time. Owners shall permit entry to their property for the persons to perform inspections.

(F) Drawings to show changes shall be submitted when changes are made to the original plans including, without limitation, changes in incremental dam crest heights, spillway locations and cross sections.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.420, 236.425, 236.435, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.420, RSMo 1979; 236.425, RSMo 1979; 236.435, RSMo 1979; 236.440, RSMo 1979; and 236.465, RSMo 1979.*

10 CSR 22-3.050 Safety Permit Requirements

PURPOSE: The purpose of this rule is to itemize the requirements for a safety permit.

(1) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020, the safety permit application for a conventional dam and reservoir shall include:

(A) Notification of the completion of construction and application for the first safety permit for the dam and reservoir shall be provided by the owner. The experienced professional engineer or agency engineer who was

in responsible charge of the construction work shall certify that the construction was substantially in accordance with the approved plans and specifications. If revisions have been made which vary considerably from the provisions of the construction permit, it must be shown that the revisions do not endanger public safety, life or property. This subsection shall not be construed to excuse any person from the requirement to notify the council or chief engineer of modifications or revisions prior to commencing the actions and to obtain the required permits or authorization thereof;

(B) Notification of completion shall be within two (2)-months' time after completion of construction; and

(C) As-built drawings shall be submitted.

(2) In addition to the basic requirements for all permits listed in 10 CSR 22-3.020, the application for a safety permit for an industrial water retention dam and reservoir shall include:

(A) Notification of completion of the starter dam or the initial phase of construction shall be prepared by or under the supervision of an experienced professional engineer and shall indicate that construction was performed in accordance with the provisions of the construction permit.

(B) Notification of the completion of construction and application for the first safety permit for the dam and reservoir shall be provided by the owner. The experienced professional engineer who was in responsible charge of the construction work shall certify that the construction was substantially in accordance with the approved plans and specifications. If revisions have been made which vary considerably from the provisions of the construction permit, it must be shown that the revisions do not endanger public safety, life or property. This subsection shall not be construed to excuse any person from the requirement to notify the council or chief engineer or modifications or revisions prior to commencing the actions and to obtain the required permits or authorization therefore;

(C) Notification of completion shall be within two (2)-months time after completion of construction; and

(D) As-built drawings shall be submitted.

(3) Visits for the purpose of observation of operation and maintenance procedures may be made by the council, the chief engineer or a member of their staff. Visits will be at any reasonable time following reasonable notice, except that in the case of an emergency threatening public safety, life or property, no notice shall be required and inspection may be made at any time. Owners shall permit entry to their property for such persons to perform the inspections.

AUTHORITY: sections 236.400, 236.405, 236.415, 236.420, 236.425, 236.440 and 236.465, RSMo 1986. Original rule filed April 14, 1981, effective Aug. 13, 1981. Amended: Filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.415, RSMo 1979, amended 1995; 236.420, RSMo 1979; 236.425, RSMo 1979; 236.440, RSMo 1979; and 236.465,RSMo 1979.*

Rules of
Department of Natural Resources
Division 22—Dam and Reservoir Safety Council
Chapter 4—Action Taken by Council and Chief Engineer

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Title 10—DEPARTMENT OF NATURAL RESOURCES
Division 22—Dam and Reservoir Safety Council
Chapter 4—Action Taken by Council and Chief Engineer

10 CSR 22-4.010 Emergency Action

PURPOSE: The purpose of the rule is to define the way emergency action is taken.

(1) In performing his/her duties, the chief engineer shall determine by inspection whether a dam or reservoir constitutes a threat to public safety, life or property. If it is determined that a dam is in an advanced state of deterioration and in such condition that continued deterioration could cause failure of the dam, the chief engineer may classify the dam as dangerous to public safety, life or property. If the chief engineer or council further determines that there is not sufficient time to issue an enforcement order to the owner to correct the hazard, or to take other legal action, the chief engineer may take any appropriate action necessary for emergency protection of public safety, life or property. The type of action depends upon the state of progression of the deterioration, the physical layout of the dam, reservoir and inundation zone below the dam, and the resources available to the chief engineer or council at the time of the emergency.

(2) The chief engineer or council, upon determining that a dam or reservoir is dangerous and constitutes a substantial threat of failure and flooding, may request the attorney general or a prosecuting attorney to take any legal steps necessary for the protection of public safety, life or property. Action may be brought in any county where the defendant or defendant's principal place of business is located or where the dam or reservoir is located. Nothing in this section shall preclude the chief engineer or council from taking immediate action under 10 CSR 22-4.010(1) with respect to any dam or reservoir that has been classified as dangerous to public safety, life or property.

AUTHORITY: sections 236.400, 236.405, 236.420, 236.425 and 236.455, RSMo 1986. Original rule filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.420, RSMo 1979; 236.425, RSMo 1979; and 236.455, RSMo 1979.*

10 CSR 22-4.020 Enforcement Orders and Enforcement Procedures

PURPOSE: The purpose of this rule is to identify the procedure to be taken for the issuance of enforcement orders.

(1) Enforcement orders shall be prepared by the chief engineer or council in cases where a dam or reservoir contains serious defects which pose a threat to public safety, life or property. Enforcement orders shall be sent to a dam owner by certified mail or served personally.

(2) If an owner does not initiate corrective actions to his/her dam and reservoir within thirty (30) days of the issuance of an enforcement order by the chief engineer or council, the council may request the attorney general or a prosecuting attorney to apply to the circuit court having jurisdiction to enforce compliance. Nothing in this section shall preclude the chief engineer from taking immediate action under 10 CSR 22-4.010(1) with respect to any dam or reservoir s/he has classified as dangerous to public safety, life or property.

AUTHORITY: sections 236.400, 236.405, 236.410, 236.415, 236.445 and 236.450, RSMo 1986. Original rule filed June 14, 1984, effective Jan. 1, 1985.*

**Original authority: 236.400, RSMo 1979; 236.405, RSMo 1979, amended 1993, 1995; 236.410, RSMo 1979, amended 1992; 236.415, RSMo 1979, amended 1995; 236.445, RSMo 1979; and 236.450, RSMo 1979.*

Missouri Revised Statutes

Chapter 236
Dams, Mills and Electric Power

August 28, 2010

Dams across nonnavigable streams--who may erect.

236.010. Any person or corporation chartered and organized to construct, operate and maintain mills, electric power and light works, or other machinery, may erect a dam across any watercourse, not being a navigable stream, if such person or corporation is the proprietor of the land through which the watercourse runs at the point where it is proposed to erect such dam, by proceeding as herein provided.

(RSMo 1939 § 10286)

Prior revisions: 1929 § 9157; 1919 § 7399; 1909 § 5456

Owner of land on one side of stream may erect dam.

236.020. Any person or corporation chartered and organized to construct, operate and maintain mills, electric power and light works, or other machinery, being the owner, in fee simple, of the land on one side of such watercourse, including a part of the bed of the stream, at a point where it is proposed to erect a dam, may, nevertheless, erect such dam by proceeding as herein provided.

(RSMo 1939 § 10287)

Prior revisions: 1929 § 9158; 1919 § 7400; 1909 § 5457

Petition to be filed in circuit court--contents.

236.030. In the case supposed in section 236.010, the person or corporation proposing to erect a dam shall file a petition in the circuit court of the county in which it is proposed to erect such mill, electric power and light works, or other machinery, in connection with the dam, and shall therein set forth:

(1) A description of the land and an abstract of the title thereto;

(2) The name of the watercourse, and a description of the point at which it is proposed to erect such dam;

(3) The altitude of the dam which it is proposed to erect; and

(4) The kind of mill, electric power and light works, or other machinery, which it is proposed to connect with the dam.

(RSMo 1939 § 10288)

Prior revisions: 1929 § 9159; 1919 § 7401; 1909 § 5458

Additional information to be set out.

236.040. In the case supposed in section 236.020, the person or corporation proposing to erect a dam shall file a petition as provided in section 236.030, and in addition thereto shall set forth:

(1) The name and place of residence of the owner of the land on the other side of the watercourse whereon to abut such dam;

(2) On what side of the watercourse it is proposed to erect such mill, electric power and light works, or other machinery in connection with the dam; and

(3) A prayer that the title to one acre of the land on the opposite side of such watercourse, to include the place where to abut such dam, may be decreed to such person or corporation, and that the same may be set apart by metes and bounds.

(RSMo 1939 § 10289)

Prior revisions: 1929 § 9160; 1919 § 7402; 1909 § 5459

Petition, where filed.

236.050. Such petition shall be filed in the circuit court of the county within which the petitioner proposes to erect such mill, electric power and light works, or other machinery.

(RSMo 1939 § 10290)

Prior revisions: 1929 § 9161; 1919 § 7403; 1909 § 5460

Writ of ad quod damnum.

236.060. Upon filing the petition, it shall be the duty of the court to cause a writ of ad quod damnum to be issued, under the seal of the court, directed to the sheriff, commanding him to summon twelve fit persons of his county to meet at the place where it is proposed to erect a dam, on a day to be named in the writ, then and there to inquire, by the said jury, touching the matters contained in the petition a copy of which shall accompany the writ.

(RSMo 1939 § 10291)

Prior revisions: 1929 § 9162; 1919 § 7404; 1909 § 5461

Duty of sheriff in executing writ.

236.070. The sheriff shall attend the jury on the day and at the place appointed, and upon full examination, inquire by such jury:

(1) What damage each proprietor will sustain by reason of inundation consequent upon the erection of the dam, as proposed;

(2) Whether the mansion house of any such proprietor, or the outhouses, curtilages or gardens thereto

immediately belonging, or orchard, will be overflowed thereby;

(3) Whether and to what extent ordinary navigation and the passage of fish will be obstructed by such erection, and whether and by what means the same may be prevented or diminished; and

(4) Whether the health of the neighborhood will be materially affected in consequence of such erection.

(RSMo 1939 § 10292)

Prior revisions: 1929 § 9163; 1919 § 7405; 1909 § 5462

Acre of ground to be set apart, when.

236.080. In the case supposed in section 236.020, the sheriff shall further inquire by the jury the value of the acre of land mentioned in the prayer of the petition, and set apart the same by metes and bounds.

(RSMo 1939 § 10293)

Prior revisions: 1929 § 9164; 1919 § 7406; 1909 § 5463

Proprietor to be notified of the inquest.

236.090. In such case the sheriff shall give the proprietor of the land whereof one acre is prayed for, a reasonable notice of the time and place when and where he will take the inquest of the jury, if such proprietor be in his county, and if not, he shall set up notice at the house of the tenant of such land, and if there be no actual tenant thereof, he shall set up such notice at some conspicuous place on the land.

(RSMo 1939 § 10294)

Prior revisions: 1929 § 9165; 1919 § 7407; 1909 § 5464

Sheriff and jury may act in adjoining county.

236.100. The sheriff and jury may enter and act in an adjoining county when necessary to the discharge of their duties.

(RSMo 1939 § 10295)

Prior revisions: 1929 § 9166; 1919 § 7408; 1909 § 5465

Inquest to be in writing.

236.110. The inquest of the jury shall be reduced to writing, signed by each of the jurors, and returned by the sheriff, together with the writ and a statement of the manner in which he executed it, into the court whence it issued, without delay.

(RSMo 1939 § 10296)

Prior revisions: 1929 § 9167; 1919 § 7409; 1909 § 5466

Proceedings on return of inquest.

236.120. Upon the return of such inquest and writ, any person aggrieved by the verdict of the jury may file his objections to the proceedings under such writ, and to the verdict, and show cause why the proceedings should be quashed and the verdict set aside.

(RSMo 1939 § 10297)

Prior revisions: 1929 § 9168; 1919 § 7410; 1909 § 5467

Issues to be tried as in civil cases.

236.130. The court may thereupon direct issues to be made up and tried as in other civil cases, and if good cause be shown therefor, the court shall quash the proceedings and set aside the verdict.

(RSMo 1939 § 10298)

Prior revisions: 1929 § 9169; 1919 § 7411; 1909 § 5468

Costs, how adjudged.

236.140. The costs attending the trial of such issues shall be adjudged against the unsuccessful party, as in other civil cases.

(RSMo 1939 § 10299)

Prior revisions: 1929 § 9170; 1919 § 7412; 1909 § 5469

Court may order new writ.

236.150. The court, on motion, may order a new writ of ad quod damnum to issue, for the purpose of having the damages assessed according to law.

(RSMo 1939 § 10300)

Prior revisions: 1929 § 9171; 1919 § 7413; 1909 § 5470

Court may enter order to erect dam, when.

236.160. If no objections be filed to the proceedings under the writ or to the verdict of the jury, and it shall appear to the court, upon a view of the inquest, that the mansion house of any proprietor, or the outhouse, curtilages or gardens thereto belonging, or orchard, will not be overflowed, and that the health of the neighborhood will not be materially affected by the stagnation of water consequent upon the proposed erection, the court shall thereupon grant or refuse the permission prayed for, according to its judgment of what would be most reasonable and just under all circumstances.

(RSMo 1939 § 10301)

Prior revisions: 1929 § 9172; 1919 § 7414; 1909 § 5471

Court shall include in its order, what.

236.170. When the party petitioning prays for an acre of land whereon to abut his dam, the court shall include in its order, if the petition is granted, a judgment vesting the title of such acre of land in the party petitioning, his heirs and assigns forever.

(RSMo 1939 § 10302)

Prior revisions: 1929 § 9173; 1919 § 7415; 1909 § 5472

Privilege to erect subject to certain conditions.

236.180. The judgment and order authorized by sections 236.160 and 236.170, and the rights and privileges thereby granted, shall, in all cases, be upon and subject to the conditions following:

(1) Such conditions in reference to the obstructions to the passage of fish and ordinary navigation, as the court shall think proper to impose;

(2) That all damages and valuations assessed and made by the jury shall be paid;

(3) That the dam and mills, electric power and light works, or other machinery, shall be commenced within one year, and finished and ready for business within three years from the date of the order of permission;

(4) That whenever the dam or mill, electric power and light works, or other machinery, shall be destroyed or materially impaired, the same shall be built or repaired within three years thereafter; but if the owner of such dam or mill, electric power and light works, or other machinery, shall be an infant, or of unsound mind, or imprisoned at the time such dam or mill, electric power and light works, or other machinery, shall be destroyed or materially impaired, then within three years after such disability is removed.

(RSMo 1939 § 10303, A. 1949 S.B. 1080)

Prior revisions: 1929 § 9174; 1919 § 7416; 1909 § 5473

CROSS REFERENCE:

Dam owners to maintain fishways--fish hatchery in lieu of fishway, 252.150

Land decreed for mill privileges to revert, when.

236.190. In case of noncompliance with any of the conditions concerning the building, rebuilding or repairing, where the land of another shall have been adjudged by the court for the purpose of an abutment, the same shall revert to and revest in the original owner, his assigns or legal representatives.

(RSMo 1939 § 10304)

Prior revisions: 1929 § 9175; 1919 § 7417; 1909 § 5474

Height of dam, how increased.

236.200. Any owner of any dam or mill, electric power and light works, or other machinery, erected by virtue of this or any previous law, may increase the altitude of his dam by permission of the court, under and by the same proceedings, regulations and conditions herein provided.

(RSMo 1939 § 10305)

Prior revisions: 1929 § 9176; 1919 § 7418; 1909 § 5475

Inquest not to bar right of action, when.

236.210. The inquest of the jury, or the order and permission of the court founded thereupon, shall not bar any prosecution or action for injuries caused by the erections herein contemplated, except such as were actually foreseen and estimated by the jury.

(RSMo 1939 § 10306)

Prior revisions: 1929 § 9177; 1919 § 7419; 1909 § 5476

Power of court to prevent erection of dam.

236.220. The circuit court of the proper county shall have power, upon petition, to prevent the erection or raising of any dam, stoppage, or obstruction across any stream which shall operate as a nuisance and be injurious to any mill, electric power and light works, or other machinery erected, or which shall dam up and render impure or unwholesome or unhealthy the waters of said stream at any point where water is or may be taken from said stream to supply the inhabitants of any city or town or village in the state with water, or of any dam, the erection of which has been authorized by the order of any competent tribunal, of a date earlier than that permitting the erection and raising of such first mentioned dam, stoppage or obstruction; and such court may, upon a final hearing of such petition, order and adjudge that such dam, stoppage or obstruction be abated by the sheriff of the proper county.

(RSMo 1939 § 10308)

Prior revisions: 1929 § 9179; 1919 § 7421; 1909 § 5478

Dams without chutes declared nuisances.

236.230. Every person who shall erect or maintain, or cause to be erected or maintained, in or across any of the waters of this state, unless said waters be wholly upon his own premises, any dam or other obstruction, no matter for what purpose, and shall not place and maintain thereon an apron or chute not less than fifteen feet wide, and sloping from each side to the center, so that the center shall be at least six inches lower than either edge, and having an inclination of not more than forty-five degrees, and so situated that the main current of water, impeded in its natural flow by the dam or other obstruction, shall pass over the same, or who shall not so construct or arrange such dam or other obstruction that it shall be lowest at the point where the apron or chute shall be placed, and low enough for the free passage of fish over the same each way, whenever the stream in which the same shall be situate shall be swollen beyond its ordinary size, shall be guilty of a misdemeanor, and shall be held to be guilty of a distinct offense each day he shall be in default as aforesaid; and every dam or other obstruction erected or maintained in violation of this section, shall be a public nuisance, and may be abated as such.

(RSMo 1939 § 10312)

Prior revisions: 1929 § 9183; 1919 § 7425; 1909 § 5482

Dams deemed public nuisances, when.

236.240. All dams, stoppages and obstructions not made according to law shall be deemed to be public nuisances, and may be dealt with as such.

(RSMo 1939 § 10309)

Prior revisions: 1929 § 9180; 1919 § 7422; 1909 § 5479

Forfeiture of rights, when.

236.250. If any person or corporation, or his or its legal representatives, to whom permission to erect a dam by virtue hereof shall have been given, shall fail to build, rebuild or repair the same, together with the mill, electric power and light works, or other machinery connected therewith, according to the requirements of law or the conditions of the permission, it shall be lawful for any person owning the land on one side of the watercourse, at the point where such dam is erected, or below, to build a dam and mill, electric power and light works, or other machinery thereon, as if no such permission had been given, without incurring any liability on account of backing the water on such dam.

(RSMo 1939 § 10310)

Prior revisions: 1929 § 9181; 1919 § 7423; 1909 § 5480

Dam reconstructed and maintained when used for other purposes.

236.255. In any case where a dam has been erected for a period of thirty years or more, and property above the dam within one mile of the point where the dam is situated has been developed for use of the impounded waters above the dam, the owner of the land on either side of the stream at the point where the dam is located shall have the right and authority to repair, maintain or reconstruct the dam, even though the dam is not used for the operation of any mill, electric power and light works, or other machinery.

(L. 1953 p. 669)

Privilege to construct dam to cease, when.

236.260. If the improvement of the navigation of any stream shall be undertaken by the state, or by any county, or other lawful authority under the state, then the privilege of keeping any dam across such stream, the right to construct which may be hereafter granted, shall cease, if the same would prevent or obstruct the making of such improvement; and it shall be the duty of the owner or owners of such dam, either to remove it or to make such change in the same as will render the navigation safe and convenient, according to the plan of such improvement; said change or alteration in such dam shall be so constructed as to be approved of by the proper officers or agents who shall have the superintendence of the improvement of such stream.

(RSMo 1939 § 10311)

Prior revisions: 1929 § 9182; 1919 § 7424; 1909 § 5481

Penalty for building without permission.

236.270. Any person who shall build or heighten any dam, or any other stoppage or obstruction on or across any watercourse, without first obtaining permission from the court of the proper county, according to law, and shall thereby work any injury to any other person, shall forfeit to the party injured double damages for such injury, to be recovered by civil action.

(RSMo 1939 § 10307)

Prior revisions: 1929 § 9178; 1919 § 7420; 1909 § 5477

Right to divert stream through tunnel--conditions.

236.280. Any person or persons, firm or firms, corporation or corporations, owning lands extending across the neck of any bend in any of the rivers of this state where a tunnel through such bends would create a waterfall to create electric power, that such owner or owners shall have the right to tunnel through such bends in such neck, on his or their or its own land or lands, and take up and divert and transmit and use the waters of said river (leaving enough water in said river at the point where said diversion shall be made to meet the wants of stock and the families below such point of diversion), and use the waters so diverted to create electric power for transmission and sale to the public, and then return such waters to said river again, without the consent of the riparian owners thereof owning shore lands on the inside and outside of said bend, between the intake and output points of said tunnel, by the use of the usual condemnation proceedings in the circuit court of the county of this state in which said lands, or a part thereof, are, or may be situated, to ascertain and establish the damage that will accrue to such owner or owners of said riparian rights by reason of the use and license aforesaid, and after this has been established and decreed, and that the judgment so awarded shall be paid before diverting and using said waters.

(RSMo 1939 § 10313)

Prior revisions: 1929 § 9184; 1919 § 7426; 1909 § 5483

Definitions.

236.400. As used in sections 236.400 to 236.500, standards, rules and regulations promulgated hereunder, unless the context otherwise requires the following words and terms mean:

(1) "Agricultural dam", any dam constructed to impound water for use in irrigation, livestock watering, or commercial fish rearing and sale;

(2) "Alterations", "repairs", or either of them, such alterations or repairs as affect the safety of a dam or reservoir, or public safety, life or property;

(3) "Chief engineer", the head of the dam and reservoir safety program of the department of natural resources or his representative;

(4) "Construction permit", a written authorization issued by the council giving the owner the right to construct, alter, enlarge, reduce, repair or remove a dam or reservoir or appurtenances thereto, with such conditions as are necessary to adequately protect the public safety, life, property, the dam or reservoir;

(5) "Dam", any artificial or manmade barrier which does or may impound water, and which impoundment has or may have a surface area of fifteen or more acres of water at the water storage elevation, or which is thirty-five feet or more in height from the natural bed of the stream or watercourse measured at the downstream toe of the barrier or dam, if it is not across a streambed or watercourse, together with appurtenant works. Sections 236.400 to 236.500 shall not apply to any dam which is not or will not be in excess of thirty-five feet in height or to any dam or reservoir licensed and operated under the Federal Power Act;

(6) "Dam and reservoir safety council", as designated by sections 236.400 to 236.500 and referred to as the "council" shall consist of seven members appointed by the governor according to the provisions of sections 236.400 to 236.500;

(7) "Director", the director of the department of natural resources of the state of Missouri;

(8) "Enlargement", any change in or addition to an existing dam or reservoir which raises the height of a dam, increases the watershed for a reservoir, or raises the water storage elevation of the water impounded by a dam or reservoir;

(9) "Experienced professional engineer", an engineer registered in the state of Missouri and experienced in hydraulics, hydrology and civil engineering as applied to dam design and construction;

(10) "Maintenance", the proper keeping of all aspects of a dam or reservoir and appurtenances thereto, that pertain to safety, in a state of repair and working order as necessary to comply with sections 236.400 to 236.500, any permit hereunder, and protect public safety, life and property;

(11) "Natural physical changes", those changes not directly or indirectly caused by man which affect the safety of the dam or reservoir;

(12) "Operation", the physical changes, natural or manmade that occur or are made to a dam or reservoir, or operation of the mechanisms or appurtenances of the dam or reservoir, which affect or may affect public safety, life or property;

(13) "Owner", a person who owns, controls, operates, maintains, manages, or proposes to construct a dam or reservoir including:

(a) The state and its departments, institutions, agencies, and political subdivisions, but not the United States government;

(b) A municipal or quasi-municipal corporation;

(c) A district;

(d) A public utility;

(e) A natural person, firm, partnership, association, corporation, political subdivision, or legal entity;

(f) The duly authorized agents, lessees, or trustees of any of the foregoing;

(g) Receivers or trustees appointed by any court for any of the foregoing;

(14) "Permit", a construction, safety or registration permit;

(15) "Permit applicant", an owner who applies for a construction, safety or registration permit;

(16) "Reduction", any decrease in the height of a dam, watershed size, or water storage elevation of the water

impounded by a dam or reservoir;

(17) "Registration permit", a permit issued for a period not to exceed five years by the council to the owner of a dam or reservoir in existence on September 28, 1979, or which becomes subject to the provisions of sections 236.400 to 236.500 for such dams and reservoirs which are in a properly maintained condition or which have made and complied with recommendations for corrections of observed defects of the dam or reservoir and have been* examined and approved in accordance with sections 236.400 to 236.500 and standards, rules and regulations and guidelines issued pursuant to sections 236.400 to 236.500;

(18) "Reservoir", any impoundment which results from a dam as defined in sections 236.400 to 236.500;

(19) "Safety permit", a permit issued to the owner for a period of five years, or less if safety considerations so require, by the council indicating that the dam meets the requirements of sections 236.400 to 236.500 and the guidelines, standards, rules and regulations issued pursuant to sections 236.400 to 236.500, and containing such conditions as to operations, maintenance and repair as are necessary to adequately protect public safety, life and the dam or reservoir;

(20) "Water", water, other liquid or tailings;

(21) "Water storage elevation", that elevation of water surface at the principal spillway which could be obtained by the dam or reservoir were there no outflow and were the reservoir full of water;

(22) "Watershed", the area, usually expressed in acres of square miles, that contributes or may contribute surface water to a reservoir.

(L. 1979 H.B. 603 § 1)

*Words "have been" not in original rolls.

Employment of engineer and assistants--records--rulemaking, procedure.

236.405. 1. There is hereby created a dam and reservoir safety program in the department of natural resources. The council shall promulgate rules, regulations, guidelines, and standards relating to the determination of whether a dam or reservoir constitutes a danger to public safety, life or property to be effective upon approval by the director.

2. The director of the department of natural resources shall employ an experienced professional engineer as chief engineer and assistants to administer the activities of the dam and reservoir safety program.

3. The chief engineer shall be selected under the state merit system on the basis of professional experience directly related to the design and construction of dams and reservoirs.

4. The findings, opinions, and orders of the council and the chief engineer shall be kept as permanent public records in the offices of the department of natural resources.

5. No rule or portion of a rule promulgated under the authority of sections 236.400 to 236.500 shall become effective unless it has been promulgated pursuant to the provisions of section 536.024.

(L. 1979 H.B. 603 § 2, A.L. 1993 S.B. 52, A.L. 1995 S.B. 3)

Council established--members, terms, qualifications, officers--meetings--quorum--

compensation.

236.410. 1. There is hereby created a "Dam and Reservoir Safety Council", whose domicile for the purposes of sections 236.400 to 236.500 shall be the department of natural resources of the state of Missouri, for the regulation of dam and reservoir safety. The council shall consist of seven members, no more than four of whom shall be members of the same political party, appointed by the governor with the advice and consent of the senate.

2. The members of the council shall have a background of academic training or professional experience directly related to the design of dams and reservoirs. At least two members of the council shall be professional engineers registered in the state of Missouri, one of whom shall represent the general public; at least one member shall be an engineering geologist; at least one member, in addition to the professional engineer, shall be a representative of the general public; two members shall be from industry, one of whom shall be earthmoving contractors; and one member shall be the owner of a dam or reservoir. The members shall serve for a term of two years; except, of the first appointments three shall be appointed for one year. The governor shall fill any vacancy on the council and may remove any appointed member for cause. The council shall annually elect a chairman and vice chairman from among its members. The council shall meet regularly but not less than quarterly. Special meetings and hearings may be called upon delivery of written notice to each member of the council signed by the director, the chief engineer, the council chairman or four of the council members. Four members of the council shall constitute a quorum to transact the business of the council. The council shall decide all questions by a majority vote of those present and constituting a quorum. The members of this council shall not receive any compensations other than for actual travel and subsistence when acting officially as members of the council.

(L. 1979 H.B. 603 § 3, A.L. 1992 H.B. 1634)

Council's powers and duties--public hearings required--adoption of rules and regulations, procedure.

236.415. 1. The council considering recommendations of the chief engineer shall, subsequent to a public meeting, adopt, subject to the approval of the director, the general technological guidelines and the standards, guidelines, rules and regulations applicable to permits, the design, construction, maintenance, operation, alteration, repair, enlargement, reduction, removal or natural physical changes that may occur to a dam or reservoir. Violations of guidelines, standards, rules and regulations are violations of sections 236.400 to 236.500 permitting the revocation, suspension, or refusal to issue any permit required by sections 236.400 to 236.500. No standards, guidelines, rules, or regulations shall be adopted, or any amendment or repeal thereof shall be effective, except after a public hearing to be held after thirty days' prior notice by advertisement or press release, and publication as required in chapter 536 of the date, time and place of the hearing and opportunity given to the public to be heard.

2. At the hearing, opportunity to be heard by the council with respect to the subject thereof shall be afforded any interested person upon written request to the council, addressed to the chief engineer, received not later than seven days prior to the hearing and may be afforded to other persons if convenient. In addition, any interested person, whether or not heard, may submit, within seven days subsequent to the hearings, a written statement of his views. The council may solicit the views, in writing, of persons who may be affected by, or interested in, proposed rules and regulations, standards or guidelines. Any person heard or represented at the hearing or making written request for notice shall be given written notice of the action of the council with respect to the subject thereof.

3. The council upon hearing the recommendations of the chief engineer and reviewing the application for a construction or registration permit shall approve or deny the permit application. The council may delegate authority to approve or deny permit applications to the chief engineer, whose actions shall be subject to appeal to the council as provided in subsection 2 of section 236.425.

4. No standard, rule or regulation or guideline, or amendment or repeal thereof, adopted by the council shall be in force and effect until it has been approved in writing by the director and the requirements of chapter 536 are satisfied. The affirmative vote of at least four members of the council shall be required for adoption.

(L. 1979 H.B. 603 § 4, A.L. 1995 S.B. 3)

Inspection of dams and reservoirs, when--report on conditions.

236.420. The council, with the advice and assistance of the chief engineer, shall carry out a state program of inspection of dams and reservoirs in accordance with regulations adopted by the council. All dams and reservoirs in this state shall be inspected on a periodic basis to determine if they constitute a threat to public safety, life or property. The chief engineer shall submit reports to the director and the council concerning the condition of each dam or reservoir inspected, and recommendations as to any alterations or repairs needed.

(L. 1979 H.B. 603 § 5)

Chief engineer's duties--search warrants--council to hear certain appeals.

236.425. 1. The chief engineer shall administer the provisions of sections 236.400 to 236.500 by:

(1) Recommending general technological guidelines that pertain to the design, construction, maintenance, operation, use, alteration, repair, enlargement, reduction, or natural physical changes of, or that may occur to, a dam or reservoir including their removal; except that, detailed technical specifications shall not be promulgated to regulate the design, construction, operation, maintenance, use, alteration, repair or removal of a dam or reservoir. Such guidelines shall not be effective until adopted by the council and approved by the director at a public meeting, after notice requirements set forth in subsection 1 of section 236.415 herein have been satisfied;

(2) Making* recommendations concerning the issuing, continuing in effect, revoking, modifying, suspending, or denying, under such conditions as prescribed by sections 236.400 to 236.500 and such rules as may be adopted to protect public safety, life, property, dams and reservoirs, construction permits for the construction, alteration, enlargement, reduction, repair or removal of dams or appurtenances thereto, and safety and registration permits to insure continuing protection of public safety, life, property, dams and reservoirs, for all dams subject to the provisions of sections 236.400 to 236.500;

(3) Making such investigations, including hearings, as are proper to protect public safety, life and property from an unsafe dam or reservoir, and to determine whether any permits should be issued, continued, revoked, modified, suspended, or denied or whether any violations of sections 236.400 to 236.500, standards, or rules or regulations have occurred or are occurring;

(4) Entering, at any reasonable time, any private or public premises as necessary to make an investigation or inspection of a dam or reservoir, or records kept, pertaining thereto, and such inspection shall follow reasonable notice to the owner given prior to such investigation or inspection except in the case of an emergency threatening public safety, life or property, in which case such inspection or investigation may be made without prior notice. A suitably restricted search warrant, upon a showing of probable cause in writing and upon oath, shall be issued by any judge having jurisdiction, to the chief engineer or his representative for the purpose of enabling him to make the inspection.

2. The council shall meet with or hear the appeal of a permit applicant and his representative upon request of the permit applicant if the chief engineer has rejected the application for a construction, safety or registration permit.

(L. 1979 H.B. 603 § 6)

*Words "To make" appear in original rolls.

Employees, council to provide for.

236.430. The council shall retain, employ, provide for and compensate within appropriations available therefor, such consultants, assistants, and other employees on a full- or part-time basis as may be necessary to carry out the provisions of sections 236.400 to 236.500 and prescribe the times at which they shall be appointed and their powers and duties.

(L. 1979 H.B. 603 § 7)

Permits required, when, procedure to obtain--chief engineer to make recommendation--exemptions--plans to be filed.

236.435. 1. Prior to the commencement of the construction, alteration, enlargement, reduction or removal of a dam or reservoir, the owner shall apply to the council and upon satisfying the requirements of sections 236.400 to 236.500 and the rules, regulations and standards promulgated pursuant hereto, obtain a construction permit.

2. The application for a construction permit shall bear the seal and signature of an experienced professional engineer registered in Missouri or employed by a qualified engineering division of a state or federal agency regularly engaged in dam construction for soil and water conservation, or irrigation or relating to wildlife conservation and shall be accompanied by the design report and plans and specification of the proposed design, alteration, enlargement, reduction, repair or removal of the dam or reservoir.

3. Any person constructing or owning a dam or reservoir, or living or owning property in an area affected, or whose safety may be affected by such dam or reservoir may consult with the chief engineer concerning such dam or reservoir.

4. The council upon hearing the recommendation of the chief engineer shall approve or deny an application for a construction permit within forty-five days after its receipt or the completion of any hearings in connection with such application, whichever is later. The permit shall be issued upon the receipt of the application if, in the judgment of the council, requirements of sections 236.400 to 236.500 and all standards, rules and regulations hereunder are satisfied and the design will be adequate to protect the public safety, life and property.

5. The council upon hearing the recommendation of the chief engineer may reject the application if it decides that there is insufficient information to determine the safety of the proposed construction, alteration, enlargement, reduction or removal of the dam or reservoir or that the construction, alteration, enlargement, reduction or removal of the dam or reservoir would endanger public safety, life or property, or otherwise not comply with sections 236.400 to 236.500 and any rules, standards, guidelines and regulations adopted hereunder.

6. A landowner who now owns or proposes to construct an agricultural dam or reservoir which will be used primarily for agricultural purposes will be exempt from all provisions of sections 236.400 to 236.500. If the council with the advice of the chief engineer, determines that the dam or reservoir is no longer used primarily for agricultural services, it shall become subject to the provisions of sections 236.400 to 236.500.

7. Dams or their construction, alterations, enlargements, reductions or removals designed by, and their construction, alteration, enlargement, reduction or repair or removal monitored by, a qualified engineer regularly engaged in dam construction for soil and water conservation or irrigation or relating to wildlife conservation are for the purposes of such construction or other listed actions exempt from the provisions of this section except that the plans for the dam shall be filed with the chief engineer prior to construction, or other listed action. Amended plans shall be filed at the completion of construction or other listed action if there have been significant

deviations from the previously filed plans.

(L. 1979 H.B. 603 § 8)

Owner to notify council, when--council to issue safety permit--registration of existing dams, when--violations.

236.440. 1. The owner shall notify the council upon completion of construction, alteration, enlargement, or reduction of the dam or reservoir. This notification shall bear the seal and signature of an experienced professional engineer and shall be accompanied by an application for a safety permit. The owner of any dam or reservoir subject to the provisions of sections 236.400 to 236.500 shall obtain a safety permit following completion of construction.

2. Upon receipt of complete and proper application for a safety permit, including notification of completion by the owner and certification by an experienced professional engineer that the new construction, alteration, enlargement or reduction has been completed in accordance with the provisions of the construction permit and sections 236.400 to 236.500, the council shall upon receipt of the application issue a safety permit. The council upon advice of the chief engineer may deny the application if it determines that violations of the construction permit or sections 236.400 to 236.500 exist. If revisions have been made which vary substantially from the provisions of the construction permit, it must be shown that the revisions do not endanger public safety, life or property. The safety permit for dams constructed pursuant to a construction permit issued under sections 236.400 to 236.500, may contain conditions the council upon advice of the chief engineer determines are necessary for the protection of public safety, life and property and a schedule and timetable for the dam and reservoir to achieve compliance with the construction permit and provisions of sections 236.400 to 236.500, standards, rules and regulations promulgated hereunder, but such conditions shall not be more stringent or restrictive than those contained in the construction permit.

3. Owners of dams and reservoirs in existence on September 28, 1979, shall obtain registration permits for dams of fifty to seventy feet in height within four years, and for dams up to fifty feet in height within six years of September 28, 1979, or as otherwise required by the provisions of sections 236.400 to 236.500 and rules and regulations adopted hereunder. A registration permit shall be issued by the council upon the advice of the chief engineer for dams and reservoirs only after it is determined that the dam meets the standards of sections 236.400 to 236.500 and rules and regulations hereunder, and any recommendations made by the inspecting engineer pursuant thereto.

4. Upon complete and proper application for a registration permit, on forms provided by the department of natural resources, by the owner of a dam in existence upon September 28, 1979, including a certification by an experienced professional engineer or an engineering division of a state or federal agency regularly engaged in dam construction for soil or water conservation, irrigation, or relating to wildlife conservation, that the dam has been inspected in accordance with sections 236.400 to 236.500, standards, rules and regulations and guidelines promulgated hereunder, and that the owner has complied with the inspecting engineer's or agency's recommendations necessary to correct observed defects of the dam or reservoir, the council shall, upon receipt of the application, issue a registration permit. The council upon hearing the recommendations of the chief engineer may deny the application if it determines that the owner has not complied with the inspecting engineer's or agency's recommendations.

5. For dams for which construction was completed prior to the effective date of the construction permit requirements hereunder, the registration permit may contain conditions the council upon hearing recommendations of the chief engineer determines to be necessary to bring the dam and reservoir into compliance with sections 236.400 to 236.500 and standards, rules and regulations promulgated hereunder.

6. If a dam or reservoir has been removed by the owner, the council shall issue a final approval upon notification by the owner and receipt of certification by an experienced professional engineer that the removal has been

carried out in accordance with the provisions of the construction permit issued for such removal. Failure to obtain final approval shall be a violation of sections 236.400 to 236.500.

7. The council shall issue safety permits for dams or their construction, alterations, enlargements, reductions or removals designed by, and their construction or other listed actions monitored by, a state or federal agency engaged in dam construction for soil and water conservation, irrigation or relating to wildlife conservation provided the owners obtain from such agency and file with the chief engineer a statement upon completion of the construction or other listed actions and at not greater than five year intervals, and with every application for renewal of a safety permit, that the dam conforms to the plans on file with the chief engineer and is in a safe, properly maintained condition.

8. The owner shall apply for renewal of a safety or registration permit not less than sixty days prior to expiration of the previously issued permit. The chief engineer shall determine if the dam and reservoir are essentially as described in the latest permit issued for that dam and reservoir, whether they satisfy the requirements of sections 236.400 to 236.500 and any rules, regulations, standards and guidelines adopted pursuant to sections 236.400 to 236.500 and whether any inspection conducted in connection with the permit renewal reveals any defect in the dam or reservoir which would threaten public safety, life or property. Unless the chief engineer determines that the dam and reservoir are not properly maintained, do not satisfy the requirements of the permit, act* or rules, regulations, standards and guidelines promulgated hereunder, or that defects revealed by the inspection are not corrected, the council upon hearing the recommendations of the chief engineer shall issue or renew the safety or registration permit upon forty-five days of the receipt of a complete and proper application. The council may require the owner to furnish a certification, as a part of an application to renew a permit hereunder, by an experienced professional engineer or a qualified engineering division of a state or federal agency regularly engaged in dam construction for water conservation, irrigation or relating to wildlife conservation that the dam is in a properly maintained condition and that any recommendation for correction of defects which violate sections 236.400 to 236.500, guidelines, rules, regulations and standards hereunder or which threaten public safety, life or property have been complied with and that the engineer detected no other such defects which have not been corrected.

9. If a barrier or water impoundment becomes a dam or reservoir through alteration or enlargement as defined herein, it shall be subject to the provisions of sections 236.400 to 236.500.

10. Failure to obtain and comply with a permit as required in this section is a violation of sections 236.400 to 236.500.

(L. 1979 H.B. 603 § 9)

*Word "act" apparently refers to "this act", now §§ 236.400 to 236.500.

Permit may be suspended--alteration or removal may be required--violation.

236.445. 1. If it is found that a dam or reservoir presents a threat to public safety, life or property, or that the safety of the dam or reservoir is threatened, the permit for the dam or reservoir shall be suspended and shall be reinstated only when the owner at his expense has completed the necessary alteration or has established such operational procedures as the council upon hearing the recommendations of the chief engineer deems necessary for protection of the public safety, life, property, the dam or reservoir. If necessary for such protection, the council may require the owner at his expense to remove the dam or reservoir, or if the owner refuses or neglects to act, the state may alter or remove the dam or reservoir, and the chief engineer may recover the costs of such action as provided in section 236.450.

2. If the owner refuses to alter or remove a dam or reservoir as directed when found to be a threat as set forth in sections 236.400 to 236.500, he shall be in violation of sections 236.400 to 236.500 and the permit requirements hereunder, and such action shall subject the owner to the enforcement provisions contained herein and revocation

of the permit.

(L. 1979 H.B. 603 § 10)

Removal or repair of abandoned dam--recovery of expenses.

236.450. An existing dam or reservoir which the chief engineer determines to be abandoned and considered to be a threat to public safety, life, or property may be altered, repaired, or removed upon such determination at the expense of the state of Missouri, and the chief engineer may request either the attorney general or a prosecuting attorney to bring an action in the name of the people of the state of Missouri to recover such expenses from the owner through appropriate legal processes. Such action may be brought in any county where the defendant or defendant's principal place of business is located or where the dam or reservoir is located.

(L. 1979 H.B. 603 § 11)

Emergency action authorized.

236.455. If it is determined at any time that the condition of a dam or reservoir is an imminent and substantial threat, and so dangerous to public safety, life or property as not to permit time for issuance of an enforcement order to correct the hazard, the chief engineer may take any appropriate action not prohibited by the constitution or laws of this state he deems necessary for emergency protection of public safety, life or property, and may request the attorney general or a prosecuting attorney to take any legal steps necessary to accomplish such action and to recover the cost of such measures from the owner by appropriate legal action.

(L. 1979 H.B. 603 § 12)

Transfer of ownership, notice required.

236.460. The owner shall notify the chief engineer upon the sale or other transfer of interest in a dam or reservoir, either existing or under construction, alteration or removal. The construction, safety or registration permit shall be transferred to the successive owner upon receipt of this notification and upon determination that such transfer will not endanger public safety, life, property, the dam or reservoir.

(L. 1979 H.B. 603 § 13)

Industrial water retention structures subject to provisions of sections 236.400 to 236.500--inspection--changes.

236.465. Irrespective of any other provisions of sections 236.400 to 236.500, the following provisions shall apply to the construction, alteration or enlargement of tailing, slime and settling ponds and to other similar industrial water retention structures included within the definitions of dam or reservoir in section 236.400:

(1) Applications for construction, safety or registration permits shall be submitted as provided in section 236.435 and section 236.440 except that design plans and specifications which outline any anticipated enlargement of the industrial water retention structure shall be included;

(2) It shall not be necessary to reapply for a permit each time the structure is enlarged if the enlargement plans

have been submitted in and approved with the original application, and the provisions of subdivision (3) of this section have been satisfied;

(3) Upon notification of the chief engineer, bearing the seal and signature of an experienced professional engineer, that the initial phase of construction has been completed in accordance with the provisions of the construction permit and sections 236.400 to 236.500, or if a registration permit has been issued as provided in subdivision (1) of this section, and before any enlargement is begun, and if no violation of sections 236.400 to 236.500 can be shown, a safety permit or a registration permit with special provisions that authorize the planned enlargement to the initially constructed structure shall be issued, on application, if enlargement plans were included and approved in the original application;

(4) It is not necessary to retain continuously a professional engineer after the initial stage of construction;

(5) The dam shall be inspected by an experienced professional engineer registered in the state of Missouri as required to renew the safety permit or registration permit at five-year intervals unless safety of the public, life and property require a shorter period of time;

(6) The chief engineer shall make inspections of these structures as necessary to insure adequate protection for public safety, life and property;

(7) Where it is shown that a tailings, slime and settling pond, or other similar water retention structure is subject to inspection for safety, using standards at least as stringent as those required under sections 236.400 to 236.500, by a federal or state agency and the owner notifies the council that the structure is subject to such inspection, such structures shall be exempt from the provisions of sections 236.400 to 236.500.

(L. 1979 H.B. 603 § 14)

Conduct of hearings--subpoenas--approval of final orders.

236.470. 1. At any public hearing all testimony taken before the council, or a hearing officer appointed by the council chairman, shall be under oath and recorded stenographically. The transcript so recorded shall be made available to any person upon payment of the usual charge therefor.

2. In any such hearing, any member of the council or the hearing officer shall issue in the name of the council notice of hearing and subpoenas. Subpoenas shall be issued and enforced as provided in section 536.077. The rules of discovery that apply in any civil case apply to hearings held by the council.

3. All hearings to approve, amend or repeal guidelines, standards or rules and regulations shall be held before at least four members of the council.

4. All other hearings may be held before one council member designated by the council chairman or a hearing officer who shall be a member of the Missouri bar and appointed by the council chairman. The hearing officer or council member shall preside at the hearing and hear all evidence and rule on the admissibility of evidence. The hearing officer or council member shall make recommended findings of fact and may make recommended conclusions of law to the council.

5. All final orders or determinations or other final actions by the council shall be approved in writing by at least four members of the council. Any council member approving in writing any final order or* determination or other final action, who did not attend the hearing, shall do so only after reviewing all exhibits and reading the entire transcript.

(L. 1979 H.B. 603 § 15)

*Word "of" appears in original rolls.

Immunity of officers.

236.475. In the absence of willful and wanton misconduct, no action shall be brought against the council, the chief engineer or his agents, or department employees or private individuals employed as consultants by the department for the recovery of damages caused by the partial or total failure of any dam or reservoir or through the use or operation of any dam or reservoir upon the ground that such person is liable by virtue of any of the following:

(1) The approval of a dam or reservoir or permits therefor;

(2) The issuance or enforcement of orders relating to maintenance, operation or repair of a dam or reservoir;

(3) Control and regulation of a dam or reservoir;

(4) Measures taken to protect against failure during an emergency.

(L. 1979 H.B. 603 § 16)

Judicial review of actions--administrative review required--interpretation of administrative actions.

236.480. 1. All final decisions, orders, actions or determinations made pursuant to the provisions of sections 236.400 to 236.500 are subject to judicial review pursuant to the provisions of chapter 536. No judicial review shall be available, however, until all administrative remedies are exhausted.

2. In any suit filed pursuant to section 536.050 concerning the validity of the standards, rules, guidelines and regulations promulgated hereunder, the court shall review the record made pursuant to their adoption to determine the validity and reasonableness of such standards, rules, guidelines and regulations and may hear such additional evidence as it deems necessary.

(L. 1979 H.B. 603 § 17)

Water rights preserved.

236.485. The provisions of sections 236.400 to 236.500 do not grant or diminish any right to that water entering, discharged from or impounded by a dam or contained in a reservoir.

(L. 1979 H.B. 603 § 18)

Enforcement of act.

236.490. All duly constituted officers of the law of this state or any political subdivision thereof shall aid in the enforcement of the provisions of sections 236.400 to 236.500.

(L. 1979 H.B. 603 § 19)

Legal actions for enforcement available, procedure.

236.495. 1. In carrying out the provisions of sections 236.400 to 236.500 and to the extent not inconsistent with chapter 491, the chief engineer or council may subpoena witnesses and compel their attendance, and may also require the submission of books, papers, documents or other pertinent data in any hearing or enforcement proceedings hereunder or in any case wherein a violation of this chapter is alleged. Upon failure or refusal to comply with such order or upon failure to honor a subpoena, as herein provided, the council may request the attorney general or a prosecuting attorney to apply to the circuit court having jurisdiction to enforce compliance.

2. The council may request the attorney general or a prosecuting attorney, in the name of the state, to institute a suit for injunctive relief to stop or prevent violations of the provisions of sections 236.400 to 236.500, permits, standards, orders and rules and regulations promulgated hereunder, which shall be violations of sections 236.400 to 236.500, or to restrain any violation thereof, or after written notification of violation by the council, and a reasonable time to correct such violation, for the assessment of a penalty of up to one thousand dollars per day, for each day or part thereof the violation continues to occur after such notice. Such action may be brought in any county where the defendant's principal place of business is located, where the dam or reservoir is located, or the violation does or may occur.

(L. 1979 H.B. 603 § 20)

Penalties.

236.500. 1. Any person who willfully violates any of the provisions of sections 236.400 to 236.500 is guilty of a misdemeanor and, upon conviction, shall be punished by a fine of not less than five hundred dollars nor more than ten thousand dollars, or by confinement in the county jail for a term of not less than thirty days nor more than one year, or by both such fine and confinement.

2. In the event of a continuing violation, each day that the violation continues shall constitute a separate and distinct offense.

3. Any person who willfully obstructs, hinders or prevents the council, the chief engineer or his agents or employees from performing the duties imposed by sections 236.400 to 236.500 and rules and regulations promulgated hereunder or who willfully resists the council, the chief engineer or his agents in the performance of the duties imposed on them by sections 236.400 to 236.500 and rules and regulations promulgated hereunder is guilty of a misdemeanor and, upon conviction, shall be punished as provided in subsection 1 of this section.

4. Any owner who willfully engages in the construction, repair, alteration or removal of any dam or reservoir without a construction permit or in violation of a construction permit or willfully violates the requirements of or for a safety or registration permit is guilty of a misdemeanor and, upon conviction, shall be punished as provided in subsection 1 of this section.

(L. 1979 H.B. 603 § 21)

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E.25. Montana

Is Your Dam Above Homes, Highways, or Other Structures?

Do you own or plan to build a dam above homes, highways, or other structures?

If you own or plan to build a dam, it's important to know whether the dam presents a hazard to the people and property downstream. A high hazard dam is any dam that impounds 50 acre-feet of water or more and could cause loss of life downstream in the event of a dam failure. "High-hazard" is not a description of the dam's condition. "High-hazard" refers to the potential for the loss of life downstream if the dam were to fail.

There are over 3,500 dams in Montana that impound 50 acre-feet of water or more. Of these dams, approximately 150 are classified as high-hazard.

Montana's Dam Safety Law

In 1985, Montana became one of 48 states to adopt regulations for high-hazard dams. The Montana Dam Safety Act implements a permitting process requiring that construction, maintenance, and operation of high-hazard dams be conducted in a safe manner.

It is beneficial for a high-hazard dam to be in compliance with Montana's Dam Safety Act. If a high-hazard dam is permitted under the act, a dam owner is not, in the absence of negligence, liable for damages resulting from discharges from the dam or reservoir that

continued...

exceed the 100 year flow. This provision reduces the risk of liability to a high- hazard dam owner.

Exempt from the Dam Safety Act are:

- Dams that are owned by the federal government,
- Dams inspected by the Federal Energy Regulatory Commission,
- Dams included in a mine operating permit issued by the Montana Department of Environmental Quality,
- Dams associated with facilities certified under the Major Facility Siting Act.
- Private dams on federal property, including dams on U.S. Forest Service property.

These dams are already required to meet safety standards established by other state or federal law and are exempt to prevent instances of dual jurisdiction or conflicting standards.

Hazard Classification

Construction of a new dam or alteration of an existing dam, with an impoundment capacity of 50 acre-feet or more, requires an application to the Department of Natural Resources and Conservation (DNRC) Dam Safety Program for a hazard classification. The ***impoundment capacity*** is measured to the maximum normal operating pool, which is usually the crest of the spillway. The requirements for hazard classification also apply to flood control structures that have the potential for impounding 50 acre-feet or more.

Construction Work on Deadman's Basin Dam

Construction Permit

If determination is reached that a high-hazard potential exists downstream from a dam, a construction permit is necessary before construction. ***Construction*** includes construction of a new high-hazard dam or major repair, alteration, enlargement, or removal of an existing high-hazard dam. An application for a construction permit must be accompanied by construction plans and specifications as well as an engineering design report.

The plans, specifications, and report must be prepared by a licensed professional engineer experienced in dam design and construction. Within 60 days of receiving a completed application, DNRC will issue or deny a construction permit. There is no fee associated with a construction permit application.

A construction permit is not required for performing minor and routine repairs, maintenance, or emergency repairs on a high-hazard facility.

The determination of hazard involves an evaluation of the area downstream from the dam that would be flooded in the event of dam failure. If the flood would have the potential to cause a loss of life, the dam is classified as a high-hazard structure. The hazard classification is based on the potential loss of life downstream; ***it is not an assessment of the safety of the structure.*** DNRC will make a hazard classification determination within 60 days after a complete application is received. The cost of the hazard classification determination is $125.

Painted Rocks Dam

Operation Permit

It may be necessary to obtain an operation permit from DNRC if you own or plan to own a high-hazard dam. An operation permit application must include an operation plan and an engineer's inspection report. The permit is effective for a period of no longer than 5 years. After 5 years renewal of the permit is required. The ***operation plan*** consists of reservoir operation procedures, maintenance procedures for the dam and appurtenant works, and the emergency procedures. The plan must be updated whenever the permit is renewed. Preparation of and adherence to the plan will aid in the safe operation and maintenance of the high-hazard dam. A more detailed description of an operation plan can be found in Administrative Rules of Montana Chapter 36.14.101-803. A sample of an operation plan is available from DNRC.

A periodic inspection of the high-hazard dam is necessary when the operation permit is first applied for or renewed. The minimum frequency for inspection is stated in the operation permit and is at least once every five years. The inspection must be arranged by the dam owner and conducted by a licensed professional engineer. A report of the inspection must accompany the permit application.

If, after reviewing the application, operation plan, and inspection report, DNRC determines that the high-hazard dam meets or exceeds minimum safety standards and can be safely operated and maintained, an operation permit is issued. There is no fee associated with an operation permit application. DNRC will issue or deny the permit within 90 days after receiving a complete application.

Civil Penalty

A civil Penalty of up to $1,000 per day can be assessed against a dam owner, for non-compliance with the Montana Dam Safety Act.

Eureka Dam Failure

Emergency

If a dam is in danger of failing due to structural deficiencies or severe flood conditions and poses a life threatening emergency, a dam owner may proceed with the necessary repairs or breaching without the previously described construction permit. ***DNCR must be notified immediately of any proposed emergency repairs or breaching.*** If a dam owner fails to act, DNRC may take any action necessary to safeguard downstream life and property. Costs incurred by DNRC's action during an emergency must be paid by the owner of the dam.

Complaints - Unsafe Dam or Reservoir

If you have a concern that life or property is being endangered by a dam, regardless of the capacity of the reservoir, a complaint may be filed by submitting an affidavit to DNRC. DNRC may then inspect or order an inspection of the dam unless the data, records, and inspection reports are adequate to determine that the complaint has no merit.

If the inspection discloses defects in the dam or reservoir that, in the judgment of DNRC, constitute an immediate hazard to life or property, DNRC can order the reservoir be drained, limiting its use, or taking other steps to ensure the safety of the dam. DNRC may require the owner to pay all or part of the inspection expenses.

Toston Dam

Ackley Dam

Laws, Rules and Forms

For copies of the Montana Dam Safety Act, the administrative rules, or application forms, you may write or call DNRC at the address below.

Other Information

Numerous publication are available concerning inspection guidelines, emergency and early warning plans, and other areas that may be of interest or assistance to owners of dams. Contact DNRC for more information.

Montana Department of
Natural Resources and Conservation
Water Resource Division
Dam Safety Program
1424 9th Avenue
PO Box 201601
Helena, MT 59620-1601
406-444-6613

TECHNICALLY SPEAKING… MONTANA'S TECHNICAL NOTES FOR RISK-BASED DAM SAFETY ANALYSES

Gary Fischer, P.E., Hydrometrics, Inc. and Carroll College
and
Michele Lemieux, P.E., Montana Dam Safety Program, Montana Department of Natural Resources and Conservation

Introduction

In 1999, the Montana Dam Safety Program adopted spillway design standards based on risk-based criteria and moved away from standards based on percentages of the probable maximum flood (PMF) keyed only to dam height and reservoir volume. This propelled the program into an era where spillway standards are determined by the risk of loss of life (LOL) due to dam failure, instead of just the size of the impounded reservoir. This was a good thing for some dam owners who were penalized for owning a large dam even though the dams were located in rural areas with sparse population where the chance for LOL due to failure was rare. However, since the new standards are based on breach inundation modeling and runoff hydrology of storms with very low exceedance probabilities, they have also required engineers to have a thorough understanding of storm hydrology and to be adept at computer modeling of storm routing and breach failures. The myriad of data available to engineers to conduct such modeling can be overwhelming and it is sometimes hard for engineers to stay abreast of the latest techniques and available information. In response to this relatively new approach to dam safety analyses, the Montana Dam Safety Program has contracted with Hydrometrics, Inc. to initially develop three Technical Notes designed to assist and provide guidance to professionals for dam safety analyses. This paper provides a description of the first two Technical Notes, with a look ahead at the anticipated features of the third.

What Would Washington State Do?

The Montana Dam Safety Program has long held a close working relationship with the Washington Dam Safety Office. The two states share similar geographical features, both having mountainous terrain in the western third of each state with the eastern two-thirds comprised of mostly high elevation plains. While Washington experiences roughly 2 to 3 times the annual precipitation and much higher population in the western third of their state compared to Montana, the eastern plains areas of both states are similar in meteorology and population. Holding similar philosophies in terms of risk-based standards, Montana in the late 1990s developed spillway standards using Washington's risk-based standards as examples. Montana's state-specific extreme storm studies were conducted using the same statistical analyses as Washington. Similar in concept to the Washington State Dam Safety Office Guidance Documents (1), the Montana Dam Safety Program is in the process of developing technical notes that provide information for professionals and engineers to conduct spillway capacity analyses, LOL determinations, and simplified evacuation mapping.

The Evolution of Spillway Standards in Montana

In Montana, a dam is regulated as “high hazard” if its failure has the potential for causing LOL. The original Dam Safety Rules established spillway hydrologic standards for high hazard dams based on reservoir volume and dam height. It became evident that in many cases the required spillway size was disproportionate to the level of downstream development. This was particularly true for large dams located in rural areas or, on the other end of the scale, for smaller dams that had dense downstream development but still posed significant threats to downstream populations.

To help address this discrepancy, the Montana Dam Safety Program within DNRC in 1999 developed new hydrologic standards that provide a uniform level of downstream protection by relating the required spillway size to the consequences of a dam failure, or estimated LOL, rather than to the size of the dam. The minimum inflow design flood, or IDF, is the storm runoff that enters a reservoir impounded by a dam and is routed through the spillway. The magnitude, or relative size, of the IDF is determined by LOL, which in turn dictates the spillway capacity to safely pass the routed IDF.

Current standards require that an IDF for LOL of 0.5 or less must have a minimum recurrence interval of 500-years. For LOL greater than 0.5 and less than or equal to 5, the minimum recurrence interval used for calculating the IDF is determined by multiplying the LOL by 1,000. In other words, for a dam with LOL potential of 3, the IDF would have a recurrence interval of 3,000 years. For LOL greater than 5 and less than 1,000, the minimum IDF is based upon the amount of runoff that is predicted to occur from an amount of precipitation calculated using equations that interpolate rainfall depths between the 5,000-year event (LOL = 5) and the probable maximum precipitation (PMP). The full PMP is used to determine the IDF, called the PMF, when the LOL is greater than or equal to 1,000. (2)

Montana-Specific Hydrologic Data

Since the new standards require estimates of runoff for precipitation storms having recurrence intervals up to 5,000 years, it was important to obtain meteorological and hydrological data to match. In anticipation of the new risk-based spillway standards, the Montana Dam Safety Program initiated two studies that provided methods for determining precipitation depths and temporal hyetograph development up to a recurrence interval of 5,000 years. Both studies were conducted by the U.S. Geological Survey (USGS) Water Science Center in Helena, Montana. The first study, completed in 1997, uses precipitation gage data from three meteorologically similar regions in Montana to develop procedures for estimating precipitation depths for 2-, 6- and 24-hour duration storms having recurrence intervals up to 5,000 years (3). The second study, completed in 1998, provides methodologies to construct synthetic rainfall hyetographs using precipitation depths estimated by the 1997 report (4). In the 1998 report, storm temporal characteristics are estimated from Montana precipitation gage data using the same three homogeneous regions as the 1997 study.

A third USGS study provides procedures for estimating unit hydrographs for large runoff events in Montana at ungaged sites (5). Based on Montana stream gage data, this report provides methodologies for estimating unit hydrographs using Clark’s Method and the Soil Conservation Service (SCS) Dimensionless Unit Hydrograph Method.

The three USGS studies described above can be used for spillways whose dams have the potential for LOL equal to or less than five. For LOL greater than 5, spillway IDF will

determined either by runoff produced by the PMP or an interpolated precipitation amount between the 5,000-year depth and the PMP. In Montana, PMP estimates are determined by two National Oceanic and Atmospheric Administration (NOAA) reports: Hydrometeorological Report (HMR) 55a (6) for areas east of the Continental Divide; and HMR 57 (7) for areas west of the Continental Divide.

Armed with these studies, Montana engineers and hydrologists have the ability to reasonably estimate precipitation and runoff events for very large and infrequent storms.

Technical Note 1 – Analysis of Spillway Capacity in Montana

Even with the wealth of information available to conduct hydrologic analyses in Montana, professionals are still faced with the complicated task of piecing together both relatively new spillway hydrologic standards and technical information provided by the USGS and NOAA. The Montana Dam Safety Program provided a spillway adequacy decision tree (8), shown in Figure 1, to help in determining steps needed in conducting a spillway analysis. The procedures shown in Figure 1 reflect the risk-based spillway hydrological standards for Montana. Technical Note 1 (TN1), *Analysis of Spillway Capacity in Montana* (9) was developed to expand the procedures in Figure 1, providing a logical, comprehensive guide for determining spillway capacity for Montana high hazard dams. TN1 incorporates the technical references specific to Montana with guidance on developing a hydrologic model using the computer program HEC-HMS (Hydrological Modeling System) (10) for spillway analysis. TN1 is a guidance document for professionals with at least some knowledge of spillways and hydrological modeling. While other references and procedures are accepted by the Dam Safety Program, TN1 references and procedures are recommended because of their direct applicability to Montana dams and because of the experience gained by the Dam Safety Program in dealing with spillway analyses.

Technical Note 2 – Loss of Life Determination

Since Montana spillway hydrologic standards are risk-based, or dependent on the estimated LOL due to dam failure, it was necessary for the Montana Dam Safety Program to develop more standardized guidance for the determination of LOL. To do this, the Dam Safety Program contracted with Hydrometrics, Inc. to develop Technical Note 2 (TN2), *Loss of Life Determination for Spillway Capacity Analysis* (11). TN2 is currently in draft form and is in the process of Dam Safety Program review. TN2 is intended as a dynamic publication that will be modified as necessary to incorporate the latest and best references for estimating LOL from dam failures. At this time, the Montana Dam Safety Program recommends procedures developed by Graham of the U.S. Bureau of Reclamation (12) for determining LOL from dam failures. Graham studied data from “every U.S. dam failure that resulted in more than 50 fatalities and every dam failure that occurred after 1960 resulting in any fatalities” (ibid). Data was evaluated with regard to warning time, population at risk (PAR) and LOL. Graham concluded LOL from dam failures is greatly influenced by three main factors: the PAR or population occupying the area inundated by a dam failure flood; the warning time given to PAR exposed to the failure flood; and the severity of the flooding. Graham provides procedures and empirical equations to estimate LOL for various combinations of the three factors mentioned previously. In general, LOL is much less than PAR, particularly in low force areas, where flood depth and flow velocity are relatively low, and with sufficient warning time.

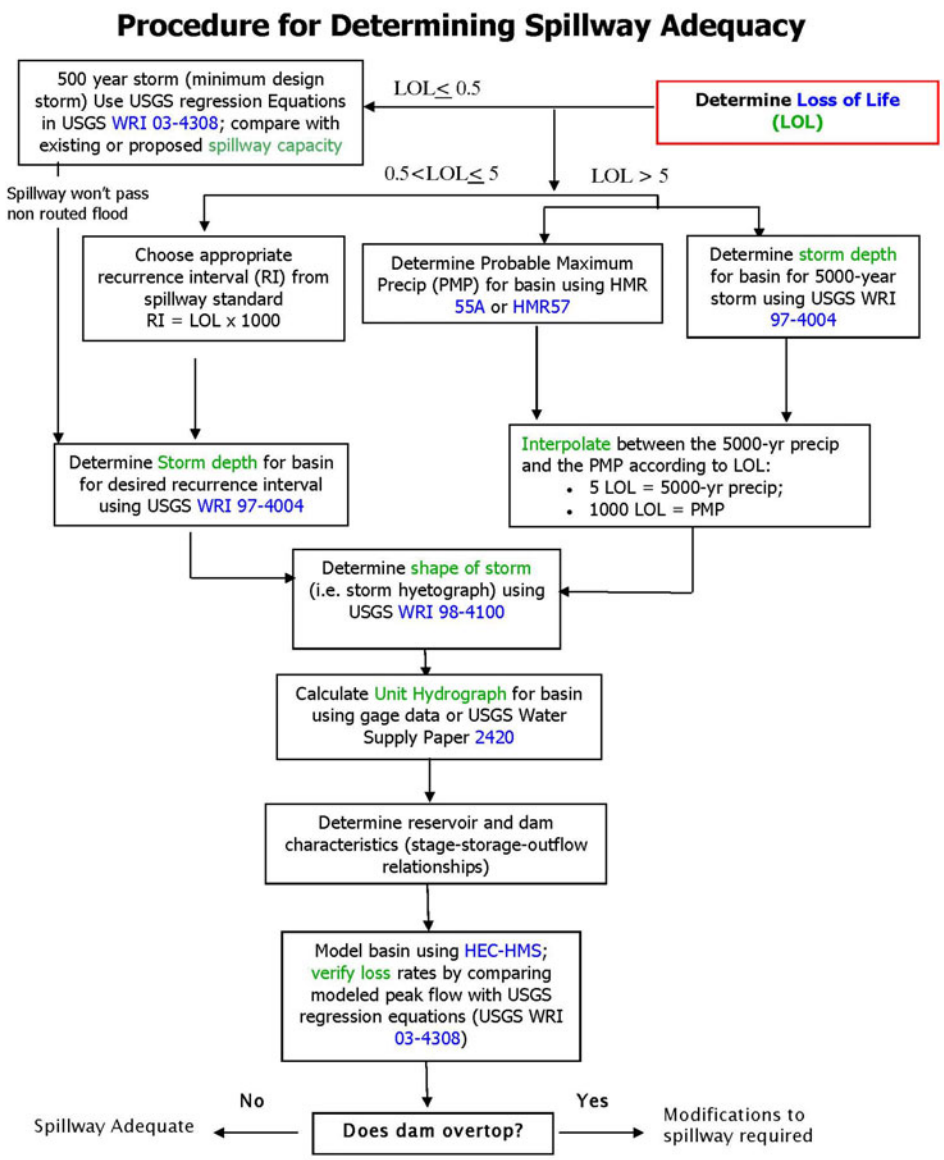

Figure 1. Procedure for Determining Spillway Adequacy for Montana Dams (8).

The Montana spillway hydrologic standards specify that the LOL determination be conducted using a simulated “spillway failure” flood (2). The Montana Dam Safety Program interprets spillway failure as the point where the spillway has exceeded its ability to discharge outflow, i.e. the spillway fails when the reservoir has reached a level at the low point of the dam crest. The modeled failure flood for an LOL determination is a result of a dam breach with the reservoir level at the crest of the dam. The failure flow does not include spillway discharge. PAR within the failure flood boundary is determined by the number of structures, roads, recreational areas and other features where humans could congregate and assigning average numbers for human occupancy. LOL is estimated using the PAR estimates, warning time, and judgment on flood severity. Flood severity according to Graham can be categorized in three levels: low severity occurs when no buildings are washed off their foundations; medium severity occurs when homes are destroyed but trees or mangled homes remain for people to seek refuge in or on; and high severity occurs when the flood sweeps the area clean and nothing remains. Obviously, professional judgment is required in assigning a severity rating. Graham recommends assigning low severity if “most of the structures will be exposed to depths of less than 10 feet and medium severity if most of the structures will be exposed to depths of 10 feet or more” (12). A final factor recommended by Graham in determining LOL is flood severity understanding. Flood severity understanding can fall within one of two categories: vague, where the issuers give the warning prior to dam failure or they are not truly aware of its potential for damage; or precise, where issuers of warnings have either seen the flooding or have relayed accurate information from others who are aware of the flooding. Figure 2 contains Graham’s table for estimating LOL based on the factors described above.

Technical Note 3 – Simplified Breach Analysis

With the need for standardizing guidance for technical evaluations using the risk-based spillway standards in Montana, the Montana Dam Safety Program also realized the need for consistent evacuation mapping and breach modeling. According to an informal survey of emergency and disaster response personnel in Montana, many emergency action plan evacuation maps tend to be confusing, especially during an emergency or emergency simulation. Evacuation maps contain at least two flood inundation boundaries, one for a clear-weather (piping) breach, and another for a storm-induced (overtopping) breach.

While these boundaries differed significantly in some cases, it was left to the emergency responder to decifer the correct boundary on the map to match the type of failure. In true emergencies, time used to read and understand maps could be time better used in issuing warnings and conducting evacuations. Other information often placed on maps, such as peak discharge travel time and flood wave height, was either ignored or misunderstood much of the time.

In an attempt to simplify evacuation maps and the engineering required to develop them, the Dam Safety Program has encouraged simplified evacuation mapping and procedures. To better explain how simplified mapping is accomplished, the Dam Safety program has tasked Hydrometrics, Inc. with developing Technical Note 3 (TN3), *Simplified Evacuation Mapping for Emergency Action Planning*. At this time, a draft version of TN3 has been written (13) and is currently being reviewed by the Dam Safety Program.

Table 7 Recommended Fatality Rates for Estimating Loss of Life Resulting from Dam Failure				
Flood Severity	Warning Time (minutes)	Flood Severity Understanding	Fatality Rate (Fraction of people at risk expected to die)	
			Suggested	Suggested Range
HIGH	no warning	not applicable	0.75	0.30 to 1.00
	15 to 60	vague	Use the values shown above and apply to the number of people who remain in the dam failure floodplain after warnings are issued. No guidance is provided on how many people will remain in the floodplain.	
		precise		
	more than 60	vague		
		precise		
MEDIUM	no warning	not applicable	0.15	0.03 to 0.35
	15 to 60	vague	0.04	0.01 to 0.08
		precise	0.02	0.005 to 0.04
	more than 60	vague	0.03	0.005 to 0.06
		precise	0.01	0.002 to 0.02
LOW	no warning	not applicable	0.01	0.0 to 0.02
	15 to 60	vague	0.007	0.0 to 0.015
		precise	0.002	0.0 to 0.004
	more than 60	vague	0.0003	0.0 to 0.0006
		precise	0.0002	0.0 to 0.0004

Figure 2. From Graham, Table for Estimating Loss of Life Resulting from Dam Failure (12)

TN3 defines the procedures to develop simplified evacuation maps. One breach flood boundary will be placed on the map to avoid confusion by emergency response personnel. The breach model will begin with a breach of the dam with the reservoir level at the low point of the dam crest. Maps will be developed in consultation with local emergency personnel in order to identify affected structures, escape routes and potential areas of backwater where additional boundaries may be added to the breach boundary. The Montana Dam Safety Program recommends breach routing modeled with the computer program HEC-HMS (10) because of its ease of use and adequate accuracy for evacuation map purposes. HEC-HMS uses pseudo-unsteady flow computational methods for flood routing, such as kinematic wave or Muskingum-Cunge, which are simplified but computationally robust. Other computer models may be used that are more sophisticated unsteady flow models, such as HEC-RAS (14) and FLDWAV (15), but to date these models can be difficult to refine in order to maintain computational consistency without program errors. The Dam Safety Program has concluded HEC-HMS provides results well within the accuracy bounds of any breach flood model, especially with the potential for uncertainty of large flood waves that may verge on non-Newtonian flow by carrying large percentages of debris and mud. HEC-HMS also tends to take less time for engineers to develop a breach model as compared to HEC-RAS or FLDWAV, reducing the cost to owners for engineering analysis.

Summary

Since the introduction of risk-based spillway standards for Montana high-hazard dams, the Montana Dam Safety Program has searched for methods to provide guidance for professionals to conduct analyses related to spillway adequacy. In 2008, the Dam Safety Program developed Technical Note 1, *Analysis of Spillway Capacity in Montana*, which is available for use by engineers and professionals, engaged in spillway analyses. Technical Note 2, *Loss of Life Determination for Spillway Capacity Analysis*, is currently in draft form and should be ready for use by professionals by mid-2010. A draft of Technical Note 3, *Simplified Evacuation Mapping for Emergency Action Planning*, has been developed and is in the process of being reviewed by the Dam Safety Program.

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36.14.502 HYDROLOGIC STANDARD FOR EMERGENCY AND PRINCIPAL SPILLWAYS

(1) Spillway conveyance for high-hazard dams will be based on estimated loss of life downstream from the dam caused by spillway failure.

(2) The minimum inflow design flood for an estimated loss of life of 0.5 or less shall be the 500-year recurrence interval flood.

(3) The minimum inflow design flood recurrence interval for estimated loss of life greater than 0.5 and less than or equal to 5 shall be determined by multiplying the estimated loss of life by 1,000.

(4) The minimum inflow design flood for estimated loss of life greater than 5 and less than 1,000 shall be determined from the design precipitation derived using the following equations:

$$P_s = P_{5,000}\ (10^{rd}) \text{ where}$$

$$r = -0.304 + .435 \log_{10} (\text{lol})$$

$$d = \log_{10} (\text{PMP}) - \log_{10} (P_{5,000})$$

lol = estimated loss of life

PMP = probable maximum precipitation

$P_{5,000}$ = 5,000-year recurrence interval precipitation

P_s = design precipitation to meet spillway standard

(5) The minimum inflow design flood for estimated loss of life greater than or equal to 1,000 shall be the probable maximum flood.

(6) The reservoir and spillway must safely store and pass the runoff resulting from the minimum inflow design flood.

(7) As a minimum, the reservoir will be assumed at normal operation pool before the minimum inflow design flood begins.

(8) The spillway capacity may be smaller if an analysis shows that there is no additional loss of life expected from the dam failure flood than that observed for the minimum inflow design flood.

History: 85-15-110, MCA; IMP, 85-15-210, MCA; NEW, 1988 MAR p. 2489, Eff. 11/24/88; AMD, 1995 MAR p. 541, Eff. 4/14/95; AMD, 1999 MAR p. 2573, Eff. 11/5/99.

Dam Safety Program

Technical Note 1

Analysis of Spillway Capacity in Montana

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DAM SAFETY PROGRAM TECHNICAL NOTE 1 (TN1)
ANALYSIS OF SPILLWAY CAPACITY IN MONTANA

Overview

Technical Note 1 (TN1) provides guidance to engineers and professionals engaged in the analysis and design of spillways for Montana high hazard dams. TN1 is intended for analyses related to high hazard dams regulated by the Montana Dam Safety Program, but the guidance provided can be used on other dams. The appropriate guidelines for specific dams are typically determined by the dam's regulating agency. The procedures in TN1 are intended for analyzing spillway capacity using the hydrologic computer model HEC-HMS (Hydrologic Modeling System). TN1 addresses only spillway capacity analysis. It does not provide guidance on armoring or erosion control design, energy dissipation, or maintenance and operation procedures.

TN1 is organized to lead the user through logical steps of spillway capacity analysis. TN1 first provides a clear explanation of spillway hydrologic standards according to Montana Dam Safety rules. Then the user is led through analysis methods to estimate factors that are used to develop a hydrologic model, such as basin characteristics, routing techniques, precipitation estimates, and reservoir and spillway characteristics. Next, TN1 provides information for the user to model precipitation and runoff with HEC-HMS as well as methods to verify the model is providing reasonable results. Finally, the appendices of TN1 provide valuable information such as design standards and flowcharts to properly analyze a spillway, model input factors and an example of a spillway capacity analysis.

TN1 is not a regulatory requirement for spillway analysis. Other methods may be used by engineers and professionals. But the guidance provided in TN1 is accepted by the Montana Dam Safety Program and the methods suggested are common in engineering practice.

We welcome comments on TN1 and contact information is provided in Section 1. We hope you find TN1 helpful and that it will serve as a reasonable approach to spillway capacity analysis.

DAM SAFETY PROGRAM
TECHNICAL NOTE 1
ANALYSIS OF SPILLWAY CAPACITY IN MONTANA

1.0 INTRODUCTION

The **Montana Dam Safety Program** is pleased to provide this **Technical Note 1 (TN1), Analysis of Spillway Capacity in Montana**. We hope this publication is helpful in providing technical guidance to professionals engaged in the analysis and design of spillways for high hazard dams in Montana. Our intent is to make available relevant and up-to-date information, references and procedures, much of which is unique to Montana, which will aid engineers and professionals in conducting spillway analyses.

This is the first Technical Note developed by the Montana Dam Safety Program and, as such, we are interested in making it the best we possibly can. We welcome and encourage your feedback on its contents. Please send your comments to:

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The Montana Dam Safety Program operates within the DNRC Water Resources Division's Water Operations Bureau.

DNRC would like to acknowledge Hydrometrics, Inc. of Helena, Montana for the development and preparation of Technical Note 1 and Mr. Rob Kingery of the DNRC State Water Projects Bureau for his review and technical guidance.

TN1 will be revised as updated technical references are made available.

1.1 PURPOSE

The purpose of TN1 is to assist and provide guidance to engineers and professionals engaged in the analysis and design of spillways for Montana high hazard dams. TN1 is not a regulatory document and the references and procedures provided can be modified to suit the needs of the user. TN1 references technical resources that are recognized as applicable to Montana dams and most often used by the Dam Safety Program in analyzing and designing spillways. The Dam Safety Program intends for TN1 to provide a consistent means of conducting spillway analyses, but recognizes that professionals may prefer other technical resources that are not used in TN1.

1.2 FOCUS AND LIMITATIONS

TN1 is intended for use on high hazard dams regulated by the Montana Dam Safety Program. Several of the technical references are specific to Montana hydrology. Guidance for federal dams may come from other sources developed for their appropriate regulations.

TN1 provides a methodology for analyzing spillway capacity using the HEC-HMS (Hydrologic Modeling System) (USACOE, 2008) rainfall-runoff model, for which data collection and input are accomplished manually. Other methods can be used to come to similar results. Where digital data is available, the use of geographical information systems (GIS) is becoming an increasingly popular and useful tool in conducting a multi-element spatial runoff model, and several available software packages and models can be used in this application.

TN1 is applicable to larger, undeveloped drainage areas, usually at least one square mile. Smaller watersheds and urban watersheds can best be modeled using other methods.

TN1 assists in evaluation of spillway capacity, but does not provide guidance on armoring or erosion control design. It also does not address energy dissipation of flows or maintenance and operation procedures.

1.3 TARGET AUDIENCE

TN1 is for use by engineers and professionals experienced in hydrologic analyses and familiar with design and rehabilitation of spillways and dams. Professional judgment is required and expected regardless of guidance provided by TN1. Users of TN1 are expected to be familiar with common hydrologic and hydraulic computer programs and their appropriate use. DNRC and the Dam Safety Program are not responsible for the use and interpretation of TN1 contents.

2.0 DESIGN STANDARDS AND PROCEDURES

Montana Dam Safety Administrative Rules govern the design, operation and maintenance of high hazard dams (dam safety rules are part of the Administrative Rules of Montana (ARM) and can be viewed at h*ttp://dnrc.mt.gov/wrd/water_op/dam_safety/*.)As described in this section, standards for Montana dams came about through a growing awareness of the potential danger of dams and the need for regular maintenance and operation procedures. This awareness started at the federal level and has become the responsibility of state agencies. The Dam Safety Program currently maintains spillway hydrologic standards based on the estimated loss of life downstream of a dam.

2.1 HISTORY OF SPILLWAY STANDARDS

The development of current spillway hydrologic standards began as an organized effort to identify potentially hazardous dams and to implement appropriate design, maintenance and operation procedures to protect downstream citizens. In the United States, the first federally-funded effort to address the safety of dams was initiated in 1972 by the National Dam Inspection Act, Public Law 92-367, which authorized the Secretary of the Army, through the Corps of Engineers, to conduct safety inspections of non-federal dams throughout the United Sates. The Corps of Engineers developed guidelines for safety inspections of dams in 1975. The guidelines recommended a two-phased study for investigating and evaluating dams. Phase 1 inspections of high hazard and other significant dams were conducted in the late 1970s and early 1980s. Results of the Phase 1 inspections were presented to state agencies responsible for dams and reservoirs. States were responsible for implementing Phase I recommendations. Phase II of the study consisted of more detailed investigations and evaluations of dams to better identify specific safety concerns. Except in special cases, the Phase II investigations were the responsibility of states.

In response to the Phase 1 reports for Montana dams, the Montana Legislature passed the Montana Dam Safety Act in 1985. The Act is currently part of the Montana Code Annotated (MCA), Title 85 (Water Use), Chapter 15 (Dam Safety Act). The Act

authorizes the DNRC to administer and implement dam safety rules and regulations. In 1988, DNRC developed the Dam Safety Rules in the Administrative Rules of Montana (ARM) Chapter 36.14.

The original Dam Safety Rules established spillway hydrologic standards for high hazard dams based on reservoir volume and dam height. The minimum inflow design flood for an existing dam impounding less than 100 acre-feet and less than 20 feet in height was the 100-year flood. The inflow design flood increased in magnitude for larger impoundments by fractions of the Probable Maximum Flood (PMF) to a maximum of the full PMF for dams impounding 50,000 acre-feet or greater and with heights of 100 feet or higher.

It became evident that in many cases the required spillway size was disproportionate to the level of downstream development. This was particularly true for large dams located in rural areas or for smaller dams that had dense downstream development. In response, DNRC searched for new hydrologic standards that would provide a uniform level of downstream protection by relating the required spillway size to the consequences of a dam failure, rather than to the size of the dam.

DNRC organized a Montana Spillway Standards Committee to develop risk-based hydrologic standards for spillways of high hazard dams and in 1999 the Committee released *Technical Decisions for Minimum Design Inflow for High Hazard Dams (Appendix B)*. The Committee recommendations were incorporated into the current Dam Safety Rules in 1999. The hydrologic standards generally require spillway capacity for high-hazard dams to be based on an estimate of the number of lives that may be lost downstream from the dam due to a spillway failure, which is called the estimated loss of life or LOL. The minimum inflow design flood, or IDF, is the storm runoff that enters a reservoir impounded by a dam and is routed through the spillway. The magnitude, or relative size, of the IDF is determined by LOL, which in turn dictates the capacity of the spillway. The IDF for an LOL of 0.5 or less must have a minimum recurrence interval of 500-years. For an LOL greater than 0.5 and less than or equal to 5, the minimum

recurrence interval used for calculating the IDF is determined by multiplying the LOL by 1,000. For an LOL greater than 5 and less than 1,000, the minimum IDF is based upon the amount of runoff that is predicted to occur from an amount of precipitation calculated using equations that interpolate rainfall depths between the 5,000-year event and the probable maximum precipitation (PMP). The full PMP is used to determine the IDF, called the probable maximum flood (PMF), when the LOL is greater than or equal to 1,000. Details of calculating IDF magnitudes are given in the following sections.

2.2 DETERMINING REQUIRED INFLOW DESIGN FLOOD

Central to the evaluation of spillways is the determination of LOL and its impact on the determination of IDF and spillway size.

2.2.1 Estimated Loss of Life Determination

One of the most subjective and misunderstood components of dam safety is the determination of LOL from dam failure. Yet this determination is the deciding factor in determining the size of the IDF for spillway design in Montana. Because of the varying approaches to calculating LOL, the Montana Dam Safety Program has provided **Technical Note 2 (TN2), Estimated Loss of Life Determination for Spillway Design**. Procedures from TN2 should be used to estimate LOL from a dam failure prior to continuing with the analysis procedures in this technical note.

2.2.2 Inflow Design Flood Determination

The method of determining the IDF for spillway adequacy depends on whether the LOL is greater, equal to or less than 5. For an LOL less than or equal to 5, the spillway IDF magnitude is calculated as a return interval, or exceedance probability of occurrence. An LOL greater than 5 requires the IDF magnitude to be calculated by equations that interpolate precipitation depths between the 5,000-year recurrence interval and the PMP.

2.2.2.1 Design Storm Frequency or Return Period for LOL ≤ 5

If the estimated LOL is equal to or less than 0.5, the minimum IDF is the 500-year recurrence interval. (Yes, LOL can be a fraction! This is part of the reason for some of the misunderstanding surrounding LOL and the need for using the procedures in TN2.)

If the LOL is greater than 0.5 and less than or equal to 5, the minimum IDF recurrence interval is determined by multiplying the LOL by 1,000.

The general equation for the return interval of the minimum IDF for LOL ≤ 5 is:

Inflow Design Flood (IDF) Return Interval = LOL x 1,000

The IDF is usually determined by applying precipitation that corresponds to the appropriate return interval to a rainfall-runoff model. Methods of determining this precipitation are described in Section 5.0. It is also feasible to determine a hydrograph for the IDF with the required return interval by conducting statistical analyses on stream gage data. However two conditions have to be met: 1) the reservoir must exist on a stream that has a nearby gage with a long-term record; and 2) the gage record must be long enough to statistically estimate peak discharges for the return interval required for dam safety purposes. For dams with LOL less than or equal to 0.5, an inflow hydrograph could be developed for the 500-year flood by first estimating the peak flood discharge using regional regression equations for ungaged basins (USGS, 2003).

Use caution when calculating the IDF based upon runoff from precipitation of a given return interval. The precipitation event with a given return interval rarely produces a flood of the same return interval. Even if two precipitation storms have identical total rainfall depths, they rarely produce equal runoff hydrographs because of differences in the temporal and spatial distribution of precipitation and variability in other basin parameters. Therefore, the user should verify rainfall-runoff model results, to the extent

possible, with established runoff statistical estimates or regional regression equations for equal return interval estimates. Section 8.0 discusses this issue in greater detail.

2.2.2.2 <u>Design Storm Precipitation Interpolation for LOL > 5</u>

If the LOL is greater than 5 and less than 1,000, the precipitation depth for determining the IDF is calculated with equations that effectively interpolate between depths for the 5,000-year storm and the PMP. The equations are found in the Dam Safety Administrative Rules of Montana, but are provided here also:

$$P_S = P_{5,000}\left(10^{rd}\right) \text{ where}$$

$$r = -0.304 + 0.435\log_{10}\left(LOL\right)$$

$$d = \log_{10}\left(PMP\right) - \log_{10}\left(P_{5,000}\right)$$

PMP = probable maximum precipitation depth (inches)

$P_{5,000}$ = 5,000-year return interval precipitation depth (inches)

P_s = design precipitation depth for the spillway standard (inches)

The IDF for an LOL greater than or equal to 1,000 is the probable maximum flood, or PMF. The PMF is runoff produced by the PMP.

3.0 BASIN CHARACTERISTICS

Basin characteristics include all physical features of the rainfall watershed contributing to the reservoir on which the dam and spillway are located. These characteristics affect the volume and timing of the resulting hydrograph from a precipitation event, and must be defined in a rainfall runoff model.

3.1 PHYSICAL ATTRIBUTES

Each drainage basin has unique physical attributes. The following sections provide insight and sources of data for each of the attributes that affect runoff.

3.1.1 Area

The area of the drainage basin is measured along the watershed boundaries or divides. A watershed is the catchment for rainfall from which runoff will flow into the reservoir. For input to HEC-HMS, the area is measured in units of square miles.

3.1.2 Subbasins

If the drainage basin has sub-areas with distinctly different characteristics or which contain separate tributaries leading to a main drainage, it can be divided into subbasins. Each subbasin can be treated as a separate rainfall-runoff unit, but the connection of each subbasin to successive subbasins or routing channels must be done in a proper sequence to model as close as possible the actual runoff flow patterns.

3.1.3 Soils

Accurate identification of soil types in the basin is essential to accurately predicting runoff. In most cases it is impractical to conduct comprehensive physical soil sampling and testing to determine soil types. If soil data are not available, some soil sampling and testing, including infiltration measurements, may be warranted as verification of estimated parameters. Soil data may not be available, especially in mountainous terrain. However, the USDA Forest Service may have unpublished data for some areas of National Forests. We advise you contact the soil scientist for the National Forest where

the drainage basin resides. For much of Montana, including state, federal and private land, there are Soil Surveys produced and published by the USDA Natural Resources Conservation Service (NRCS). The following sections describe some of the sources available for soil data.

3.1.3.1 NRCS Web Soil Survey

The NRCS provides a *Web Soil Survey* site to assist in determining soil properties for a specified "area of interest", which is in this case is a drainage basin or subbasin. The link for accessing the *Web Soil Survey* is http://websoilsurvey.nrcs.usda.gov. This site contains most of the available soil survey information for the state and is a convenient way to determine composite hydrologic soil groups. The site includes most federal land in its inventory.

3.1.3.2 NRCS Soil Surveys

NRCS Soil Surveys are published for most counties in Montana and are available. A listing of soil surveys and their availability is shown on the following web site: http://soils.usda.gov/survey/printed_surveys/state.asp?state=Montana&abbr=MT.

3.1.3.3 Other Data Sources

Soil data can be obtained from a variety of sources. It is up to the user to determine the best available data. Common sources include counties, federal and state land management agencies, colleges and agricultural research centers.

3.1.4 Land Use and Ground Cover

While soil is important in determining infiltration rates and water holding capacity, it is equally important to determine the predominant plant cover and land uses for the subject basin. These factors greatly influence precipitation loss parameters, as in determining an appropriate NRCS curve number (see Section 3.3.2.1). Commonly, thick vegetation and healthy forests create abstractions that either trap rainfall or effectively delay the runoff response, creating runoff hydrographs that have relatively low peak discharges and runoff volumes. Conversely, urbanization and human development produce impervious areas

that prevent or delay infiltration, resulting in more runoff than in a natural setting. The general effect is to produce higher runoff volumes and peak discharges in a basin.

3.1.5 Hydrologic Condition and Antecedent Moisture Condition

Hydrologic condition, according to the NRCS, refers to the factors that affect infiltration and runoff, including density of vegetative areas and surface toughness. Poor hydrologic condition indicates impaired infiltration and increased runoff, while good hydrologic condition is the opposite. Antecedent moisture condition is a measure of the soil moisture just prior to a storm event. Estimating hydrologic condition and antecedent moisture of a drainage basin depends on how much conservatism the user intends for the rainfall-runoff model. Hydrologic condition of a basin can typically be estimated based on the factors listed above. However, soil moisture constantly changes and predicting the water holding capacity of a soil just prior to a given precipitation event is not usually possible. If a basin is relatively dry, and has not experienced rainfall for a period of time, there will typically be a fairly high capacity for infiltration and the ability to retain or retard rainfall for the design storm. High soil moisture or saturated soils may be present if antecedent storms have occurred prior to the design storm. If the basin is already wet and the soil has little additional water holding capacity, more precipitation will become runoff and the resulting hydrograph will be larger than dry antecedent conditions. Hydrologic condition and antecedent moisture condition are typically accounted for in a hydrologic model by infiltration variables, which are discussed in Section 3.3.

3.2 UNIT HYDROGRAPH ESTIMATION

The most common method to define the unique shape and timing of a direct runoff hydrograph for a given drainage basin is to determine its unit hydrograph. As a review, unit hydrograph theory will be briefly described. First introduced by Sherman (1932), the unit hydrograph is defined as a hydrograph of 1 inch of rainfall excess or direct runoff (the portion of rainfall that is available for runoff after losses) for a specified rainfall duration. It is also assumed that the rainfall is distributed uniformly over the entire basin. The unit hydrograph is considered to be a function of basin characteristics. The theory of a unit hydrograph is that runoff is linearly related to rainfall excess. Therefore, direct

runoff from complex storms of any duration with sequential increments varying in depth can be estimated by superimposing and adding unit hydrographs. There are numerous hydrology reference texts available to assist the user with further details on the theory and application of unit hydrographs.

3.2.1 Hydrograph Analysis

For a reservoir on a watershed with streamflow and rainfall gage records, a unit hydrograph can be derived by a trial-and-error procedure that involves analyzing recorded runoff hydrographs and rainfall hyetographs. Users are encouraged to follow standard published methodologies if this situation applies to their project.

3.2.2 Synthetic Unit Hydrograph Development

Most applications in dam safety will involve developing a synthetic unit hydrograph on an ungaged basin. Many methods have been developed for estimating synthetic unit hydrographs, but because of the work accomplished by the USGS specifically for Montana, this technical note will focus on two related methods and include just a brief discussion of other common methods.

3.2.2.1 <u>Montana Procedures (USGS WSP 2420)</u>

USGS published *Water-Supply Paper 2420, Procedures for Estimating Unit Hydrographs for Large Floods at Ungaged Sites in Montana* (1996). This paper presents procedures for determining unit hydrograph parameters for two methods: the Clark unit hydrograph and the dimensionless unit hydrograph. The USGS study was initiated because of the subjectivity in determining unit hydrographs in dam safety applications. The Dam Safety Program recognizes *WSP 2420* as a reliable source for unit hydrograph development for dams in Montana.

WSP 2420 presents procedures derived from Montana streamflow and rainfall records. Unit hydrographs are developed for physiologically similar regions of the state. Examples in *WSP 2420* provide procedures for unit hydrograph development. Unit hydrograph parameters can be easily input into HEC-HMS for rainfall-runoff modeling.

Clark (1945) developed a method to define unit hydrographs using three components: the time of concentration (Tc); a basin storage coefficient (R); and a time-area curve. Using regression analysis of rainfall and runoff gage data, the USGS developed equations to calculate the Tc and R for the Clark unit hydrograph. Although the time-area curve may be developed independently, it is most common to utilize the default time-area curve from Figure 3 of *WSP 2420*.

The dimensionless unit hydrograph is a versatile tool when comparing drainage basins with varying characteristics. In the USGS study, unit hydrographs were made dimensionless by dividing the discharge at each time step by the "standard lag" time, as defined by Snyder (1938). This is the same procedure developed by Cudworth (1989) for the U.S. Bureau of Reclamation.

The tables and equations for using *WSP 2420* dimensionless unit hydrograph methods to calculate unit hydrographs are too extensive for this technical note, however DNRC has available a spreadsheet that will perform the calculations. This spreadsheet is available from the Dam Safety Program.

It is necessary for the user to become familiar with the concepts and procedures presented in *WSP 2420* to properly use the publication for dam safety applications. While the parameters for determining unit hydrographs were developed from Montana hydrological data, there is scatter in the data used to derive the variable regression equations and the user is encouraged to review and understand the reliability of the equations prior to unit hydrograph development. *WSP 2420* fully explains the limitations and design considerations of the study. Several limitations are as follows:

- Unit hydrograph characteristics were generally derived from general (or long duration) rainfall events instead of local (thunderstorm) events. These were some of the largest storms recorded in Montana, so they should represent the "worst-case" conditions.

- Lag time estimates in the report are not valid for use in other dimensionless unit hydrographs, such as those of the U.S. Bureau of Reclamation.
- The unit hydrograph duration needs to be small enough to reasonably estimate the peak discharge. Rules for calculating the unit duration are given in the study.
- The methods are applicable for basins small enough that variations in areal runoff do not affect the hydrograph shape. If the calculated unit duration is greater than 7 hours, the basin may require subdividing with separate unit hydrographs for each subbasin. Likewise, it is recommended that basins over 500 square miles be subdivided for the same reasons.
- Equations for adjusting the peak and shape of dimensionless unit hydrographs are invalid when the desired dimensionless peak discharge is less than 8.0.
- The study estimation methods are valid only within the range of variables used. Figures 15-19 should be reviewed to insure that the basin parameters are within the range of data used in *WSP-2420*.
- The methods are intended for use at ungaged sites where no site-specific information is available.

3.2.2.2 Other Methods

Hydrology texts describe various other methods for determining synthetic unit hydrographs. Here are brief descriptions of several of the most common methods, whose reference citations are included in the text by Viessman and Lewis (2003):

Gamma Distribution – Because the shapes of most hydrographs closely match a two-parameter gamma function, this method can be used to develop synthetic unit hydrographs. The advantage of this method is the volume under the curve can be determined to exactly equal one inch of runoff from a basin, plus it produces a line that is continuous rather than relying on the calculation of only several points to draw a curve.

Snyder's Method – Commonly employed by the US Army Corps of Engineers, this method is used in the USGS dimensionless unit hydrograph procedure to determine

standard lag time. But the full use of the method results in calculations of lag time, time base, unit hydrograph duration, peak discharge, and hydrograph time widths at 50 and 75 percent of peak flow to construct a unit hydrograph. Some coefficients vary according to types and locations of streams and drainage basins.

Espey-Altman Method – For use in primarily urban settings, this method uses a set of regression equations developed from a regional analysis of relatively small watersheds to calculate seven points on a 10-minute unit hydrograph.

NRCS Dimensionless Unit Hydrograph – Using the same general concept as in WSP 2420, the NRCS used the results of an analysis on a large number of natural unit hydrographs to develop dimensionless time and discharge coordinates for a dimensionless unit hydrograph. In order to determine the unit hydrograph coordinates, the method requires calculations of the hydrograph time from the beginning of rainfall to peak discharge and the peak discharge.

3.3 RAINFALL LOSSES

Not all rainfall becomes surface runoff. Understanding how rainfall infiltrates, is intercepted, or is stored in small ground depressions is key to determining the volume and timing of runoff. Reasonably accurate estimates of rainfall losses are difficult to determine and are probably the most subjective parameters in surface hydrology. The following sections provide guidance on some of the methods for determining rainfall losses.

3.3.1 Initial Abstraction

As defined by the NRCS, initial abstraction is the portion of rainfall that is lost before it becomes excess rainfall or surface runoff. Initial abstraction includes interception (rainfall that is held by vegetation or structures before reaching the ground), infiltration (rainfall lost into the soil before becoming saturated and reaching a point where rainfall intensity is greater than the soil infiltration rate), and depression storage (surface storage

areas that do not release trapped water during the rainfall event). Initial abstraction can be estimated by several different methods.

The most common equation for determining initial abstraction is empirical and used in conjunction with the NRCS curve number method (2007) (see Section 3.3.2.1of this technical note), which is

$I_a = 0.2S$ where I_a = initial abstraction, inches

S = potential maximum retention after runoff begins, inches = 1000/CN -10

CN = soil complex curve number

HEC-HMS offers many different methods of determining rainfall loss and initial abstractions are generally included with each method. Note that when using the NRCS curve number method (see section 3.3.2.1), if an initial abstraction of zero is entered, HEC-HMS automatically calculates an initial abstraction based on the curve number. The user is encouraged to estimate initial abstraction with whatever method is familiar, but to justify the parameters chosen.

Initial infiltration loss is included with methods on infiltration (Section 3.3.2). Other resources are available for estimating interception, such as Horton (1919) and Woodall (1984). Depression storage can be estimated from other sources as well, including Chin (2006).

Initial abstraction can be a useful tool in calibrating a surface runoff model such as HEC-HMS. Please refer to Section 8.0 of this technical note for a discussion on model verification.

3.3.2 Infiltration

Infiltration in this application refers to rainfall lost to the soil after initial abstraction, once surface runoff has started. Infiltration rates vary with soil texture. In general terms,

infiltration rates in coarse grained or sandy soils are much higher than fine grained or clayey soils. Infiltration rates for a given soil are not linear over time when water is continuously ponded at the surface. Given enough time with water ponded over the soil column, infiltration will approach a steady, constant rate. Infiltration rates can be estimated by several different methods, briefly described below:

3.3.2.1 NRCS Curve Number

The USDA Natural Resources Conservation Service (NRCS) developed the curve number model through empirical research on a broad range of soil types and cover combinations. It is probably the most popular method of determining excess rainfall, or direct surface runoff, because of its ease of application and extensive database of parameters. The curve number model divides rainfall into three components: rainfall excess (runoff), initial abstraction, and retention. Through a series of computational relationships between all three components, the NRCS developed hydrologic soil-cover complexes. Each complex was assigned a curve number, or CN, which indicates the runoff potential of a complex during periods when the soil is not frozen. High curve numbers indicate high potential for runoff. The highest possible CN is 100, which means that all rainfall becomes runoff and there are no abstractions.

In order to use the CN method, the user has to know the soil and cover types for the basin being considered. The user also has to determine the hydrologic condition of the cover vegetation (whether it is thick or sparse), and assume an antecedent soil moisture condition. Appendix C of this technical note contains tables for estimating CN for a basin.

While this method is empirically-based and has been shown to be less accurate than some physically-based infiltration models, it is one of the most widely used methods. It provides a relatively easy method to estimate rainfall losses, especially over large basins, and it is backed by the NRCS, who use this method extensively. To the extent possible, the user should verify the results of a rainfall-runoff model based on the CN method with

an independent analysis of peak discharge values and adjust CN values appropriately, as described in Section 8.0 of this technical note.

Note that curve numbers can give a quick estimate of direct runoff volume from a basin using the following NRCS equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Where Q = direct runoff in inches (which can be converted to volume by multiplying by the basin area)

P = total precipitation in inches

S = potential maximum retention of precipitation = (1000 – CN)/10

CN = curve number

3.3.2.2 <u>Constant Loss Rate</u>

The constant loss rate for infiltration is used when the assumption is that the soil is saturated and infiltration has reached a minimum, steady value. Use of this method also indicates that initial infiltration abstractions are zero. Various tables are available with estimated constant loss rate values for different soil types. The Technical Reference Manual for HEC-HMS has such a table with ranges of constant loss values for soil types used for CN estimations.

3.3.2.3 <u>Other Methods</u>

Other infiltration models are appropriate and, when properly used, provide very accurate estimates of rainfall infiltration. There are general input parameters available for these methods, but most require actual infiltration data to be effective. Data collection may be cumbersome in most applications, but these methods can precisely predict infiltration if data are available. References for the following infiltration models are included in the HEC-HMS Technical Reference Manual.

Horton Model – Derived empirically but based on physical relationships, the Horton Model is an exponential relationship that defines infiltration rate over time assuming water is continuously ponded over the soil. Infiltration declines exponentially until it asymptotically approaches a minimum constant rate.

Green-Ampt Model – Also called the delta function model, it was derived as both a physical and empirical model that assumes water is constantly ponded on the soil surface and that as the water moves downward in the soil, there is a sharp interface where wet soil meets dry soil. Infiltration is affected by soil hydraulic conductivity, wetting front suction head and porosity.

3.3.3 Percent Impervious Area

If a basin contains areas that prevent infiltration, such as frozen ground, open water bodies, pavement, rock, etc., these surfaces are accounted for in the model as "percent impervious area". This factor is used in conjunction with CN or other loss methods to estimate runoff in a storm event. Greater percentages of impervious areas produce higher runoff volumes. Therefore, if the user desires conservative (high) runoff values, then high percent impervious values are used. Percent imperious area can also be used as a calibration parameter when verifying model results.

4.0 CHANNEL ROUTING METHODS

If there is a component to the hydrologic model that requires flow of runoff in an established channel, such as a stream, river, or prismatic channel, the model will need a method specified to route the hydrograph. Channel routing is a means of transporting flow in a channel and adjacent floodplain overbanks. Routing starts with a runoff hydrograph determined from overland flow of excess rainfall, or direct surface runoff, from a subbasin. The upstream hydrograph is routed down the channel by a specified method to a known downstream point, resulting in a downstream hydrograph. Travel time through the specified reach is an indication of the hydrograph translation. Attenuation of the hydrograph (reduction of peak discharge and flattening of the hydrograph curve) occurs because of energy loss and storage as it travels downstream.

As described in Section 4.2, there are several models available for computing a downstream hydrograph using a program such as HEC-HMS. Each of these models solves, in various degrees of simplification, the fundamental equations of open channel flow: the continuity and momentum equations. Combined, the two equations are known as the St. Venant, or unsteady (dynamic wave), equations. HEC-HMS methods are simplified to the point of approximating unsteady flow using simplified approximations. These approximations typically combine the continuity equation with a simplified momentum equation that includes only relevant and significant terms. The justification for not using the solution of the full unsteady equations in HEC-HMS is that approximations of the full equations are adequate for typical flood routing needs and the approximations provide faster and more stable computational processes.

It may be necessary for some problems to use the full unsteady equations. Section 4.3 provides a brief summary of some of the models available for this application.

4.1 BASEFLOW

A runoff hydrograph is generally separated into two types of flow: direct runoff from excess precipitation and baseflow. Baseflow is usually the "normal" flow of a water course, consisting of runoff from prior precipitation or groundwater inflow that was stored temporarily in the watershed. Baseflow can also be the delayed subsurface runoff from the current storm. Some modelers try to account for the contribution of snow melt by approximating it as baseflow.

Some models of watersheds use extensive computations to account for baseflow storage and subsurface flow. This approach is appropriate for long-term watershed modeling and hydrologic budgeting. However the impact of baseflow on a short-term flood event, such as for dam safety applications, may be not as significant. HEC-HMS uses three methods for estimating baseflow, each with simplified approximations that are more appropriate for storm runoff applications:

- Constant, monthly-varying value
- Exponential recession model
- Linear-reservoir volume accounting model

Selection of the appropriate method is left to the user.

4.1.1 Considerations for Snow Melt and Rain-on-Snow

While most extreme runoff events are triggered by and modeled for only rainfall, there is the potential for significant runoff caused by snowmelt in Montana. Spring and early summer storms may occur on snowpack, creating rain-on-snow events that have the potential to be severe. Mostly notably, the June 1964 storm along the northern Rocky Mountain front that caused nearly 20 fatalities and several dam failures was a rain-on-snow event. Given the right meteorological conditions, high elevation watersheds have the potential for significant runoff from only snowmelt.

However, effective and accurate modeling of snowmelt is difficult and tends to be very data intensive. HEC-HMS offers two methods for predicting snowmelt: the gridded temperature index and the temperature index. Both methods use atmospheric conditions to determine snow accumulation and snowmelt rates. Runoff is the result of availability of liquid water at the soil surface.

Snow's contribution in hydrologic modeling can be simplified to at least estimate that portion of runoff resulting from snowmelt. If some data are available to determine reasonable estimates of runoff by snowmelt, they can be used to enhance the rainfall runoff. A typical method is to account for the snowmelt by increasing base flow by an average snowmelt discharge. Total discharge would combine the rainfall runoff and the enhanced base flow.

The NRCS maintains SNOTEL sites, which are remote, high mountain snow data collection locations, for providing snowpack runoff data that is transmitted telemetrically. SNOTEL stands for SNOwpack TELemetry. In addition to providing data that may be used to determine average or typical rates snowmelt runoff for a basin, SNOTEL sites may provide data that can be used to confirm that a spillway is sized adequately to handle the largest snowmelt event of record in addition to the spillway design inflow. For some small, high mountain dams, this maximum snowmelt rate may be larger than the spillway design inflow calculated from precipitation events.

4.2 HEC-HMS ROUTING METHODS

As mentioned previously, HEC-HMS offers routing methods that provide approximations of full unsteady flow equations. Methods should be selected based on specific uses and conditions of the routing channel and parameters of the project, and familiarity of the user with a specific method. The following are brief descriptions of the methods offered in Version 3.2 of HEC-HMS and, for some of the following methods, their applicability for routing hydrographs along channels:

Kinematic Wave Routing – This process ignores the inertial and pressure forces of the full unsteady flow equations. It is better suited for relatively steep streams and channels

that can be approximated by regular shapes and slopes, such as man-made channels. Five options are provided for determining the channel cross sectional shape: circle (for open channel flow in circular channels – not for pressure flow in a pipe), deep (for shapes where depth is approximately equal to width), rectangle, trapezoid, and triangle.

Lag Routing – This method is used only for the translation of a flood wave, or hydrograph. It does not account for attenuation or diffusion of the flood wave. It can be effectively used in short stream segments where travel time and flow depth are known and do not vary. The only input parameter for lag routing is lag time, which is the travel time for the hydrograph to move from the upstream end to the downstream end of the stream segment. It is best suited to short stream segments with a predicable travel time that doesn't vary with flow depth. This method may be overly conservative, as some attenuation always occurs.

Modified Puls Routing – Also called storage or level pool routing, this method uses a relationship between water storage in a stream reach and discharge from the reach to route flow. It is through calculated storage and delayed release of retained water that attenuation is determined. It can be used to calculate backwater from channel constrictions, as long as the backwater is contained in the stream reach. The process requires input of a storage-discharge function for each reach. This can be obtained from hydrograph analysis or by conducting a HEC-RAS analysis of the reach to determine a storage-discharge relationship. The user also determines an initial flow condition by one of three options: initial discharge; outflow equals inflow; and an elevation-discharge relationship.

Muskingum Routing – Using a basic conservation of mass computation, this method determines a water surface that is linear but is not level. By this approximation, Muskingum routing accounts for increased water storage in the rising limb of the hydrograph and decreased storage in the falling limb. By adding a travel time component, K, and an X variable that expresses the weighting between inflow and outflow in the specified reach, this method approximates hydrograph attenuation.

Muskingum-Cunge Routing – This method combines the conservation of mass and an approximation of diffusion in the conservation of momentum equation. Sometimes referred to as the variable coefficient method, it recalculates parameters at each time step with new depth and channel properties. It is sometimes referred to as a variable coefficient method because the routing parameters are recalculated every time step based on channel properties and the flow depth. It represents attenuation of flood waves and can be used in reaches with a mild slope. The user has a choice of five types of cross sections to enter into the routing procedure: rectangular, trapezoidal, triangular, circular or an eight-point section. The eight-point section makes this method useful for natural channels and is based on an average stream and floodplain cross section for the selected reach. Reaches should be determined on the basis of each having similar cross sectional properties. Manning's 'n' values for channel and left and right overbanks are to be input by the user. Manning's 'n' values should be average numbers for each reach. Note that when using HEC-HMS it often is necessary to include a baseflow when using the Muskingum-Cunge method, in order for the computations to work.

Straddle Stagger Routing – This method uses empirical representations of translation and attenuation to route flow through a specified reach. Two parameters are entered into the model: lag and duration. Lag is the approximate travel time of the hydrograph through the reach; duration defines the amount of spread in the hydrograph peak, or the amount of attenuation.

4.3 OTHER ROUTING METHODS

For more precise estimation of hydrograph routing in a channel reach, it is recommended that a hydraulic model be used to incorporate the full solution of St. Venant's equations. At this time, the most widely used and accessible computer program for accomplishing this is HEC-RAS (River Analysis System, USACOE, 2008). The advantage of unsteady flow estimation in HEC-RAS is that the physically-based equations more accurately represent floodplain storage and energy dissipation while a flood wave travels in a natural channel and floodplain corridor, as well as defining backwater profiles at channel

constrictions. At this time, HEC-RAS computational modeling of unsteady flow tends to be somewhat unstable in cases of rapidly varied flow, such as a flood wave, and the user is required to make model adjustments based on professional judgment to overcome the program instability.

The National Weather Service (NWS) developed two computational models to help forecast hydrograph routing in rivers. The first, DWOPER (Dynamic Wave Operation Model) (1984), was intended as a tool to model unsteady flow in major rivers where mild bottom slopes and backwater created problems in hydrologic routing models. The second is DAMBRK (Dam Break Model) (1988), used primarily to predict flood wave routing specifically for dam failures. Each model has limitations unique to their intended function. The NWS sought to combine features of each into one model, called FLDWAV (Generalized Flood Wave Routing Model) (1998), but at this time, access to the program is limited and utilization is primarily for NWS projects.

The United States Geological Survey (USGS) has available for public use a program titled Full Equations Model (FEQ) (1996), which is a computer model for simulation of one-dimensional unsteady flow in open channels and through control structures. According to the USGS, FEQ can be applied to simulate a wide range of stream configurations including loops and lateral-inflow conditions.

All of the programs mentioned above are one-dimensional unsteady flow models. Applications of flood flow simulation in wide, flat floodplains where flow occurs in two directions may require the use of two-dimensional models such as FLO-2D® (FLO-2D, 2007) or MIKE FLOOD® (DHI, 2008). Both models are approved by the Federal Emergency Management Agency (FEMA) for floodplain modeling and use dynamic computations for complex flow interaction. Use of these models requires a technical understanding of the two-dimensional flow regime.

5.0 PRECIPITATION ESTIMATES FOR MONTANA

For use in rainfall-runoff modeling, precipitation is the catalyst for runoff. While basin characteristics have a significant effect on the timing and volume of runoff, precipitation plays a more important role, especially with very large storms that easily saturate soil and fill small depression storage areas. Four components of precipitation need to be determined in order to fully define how runoff will occur: depth, duration, temporal distribution and spatial distribution. Depth and duration are linked by the premise that severe storms of short duration typically have higher rainfall intensities than longer duration storms. Publications specific to Montana have been developed by both the USGS and NWS to assist in precipitation estimates.

In response to the effort by DNRC to base spillway IDF on LOL from dam failure, and move away from standards based solely on reservoir size, the USGS developed methods for determining storm depth and temporal distribution up to a return interval of 5,000 years for the state of Montana. For larger storms, rainfall depths are interpolated between the 5,000-year storm and the probable maximum flood (PMF). As described earlier in this technical note, a PMF is produced by PMP estimates, which in turn are computed by methods developed by the NWS.

5.1 RAINFALL BASED ON OCCURRENCE PROBABILITY

For dams having LOL less than or equal to 5 (determined from a dam breach evaluation), and subsequently a storm return interval of between 500 and 5,000 years, the rainfall storm depth is calculated using methods developed by the U.S. Geological Survey (USGS) for extreme precipitation events. The following sections provide guidance on use of the appropriate references.

5.1.1 Storm Depth and Duration Determination (*USGS WRIR 97-4004*)

The USGS published *Water-Resources Investigations Report (WRIR) 97-4004, Regional Analysis of Annual Precipitation Maxima in Montana* (1997). This document provides methods for determining precipitation depths in Montana for extreme storms having

exceedance probabilities up to one-in-five thousand, or return intervals to 5,000 years. The study utilized statistical procedures that effectively combine record lengths of multiple rainfall gages to make depth estimates for relatively long return intervals. Dimensionless frequency curves for three homogeneous regions within Montana were developed based on physiography and climate. Precipitation depths can be computed for storm durations of 2-, 6-, and 24-hours. Mean storm depth regression equations use site mean annual precipitation, latitude and longitude as variables. The user is encouraged to follow the publication examples in *WRIR 97-4004* to determine storm depths for various applications.

5.1.2 Temporal Distribution (*USGS WRIR 98-4100*)

Following *WRIR 97-4004*, the USGS published *Water Resources Investigations Report 98-4100, Characteristics of Extreme Storms in Montana and Methods for Constructing Synthetic Storm Hyetographs* (1998), which identifies temporal distributions of incremental storm depths for 2-, 6-, and 24-hour duration storms, and their application to analyses or design. The study uses the same homogeneous regions as *WRIR 97-4004*. Starting with total storm depths determined from *WRIR 97-4004*, incremental depths are calculated and distributed to construct hyetographs according to regional statistical analyses. Peak incremental depths are temporally distributed based on historical occurrences within a specified region and the level of conservatism desired. *WRIR 98-4100* offers examples of hyetograph construction for various applications in the homogeneous regions of the state.

5.1.3 Areal Distribution

Specific spatial, or areal, distribution recommendations are not given in *WRIR 97-4004* or *WRIR 98-4100*. Spatial distribution is left to the user. It is possible to use the areal distribution procedures for some PMP estimates, discussed in Section 5.2.4. Section 5.2.4 also provides a brief discussion on the use of areal distribution within a drainage basin.

5.1.4 Areal Reduction Factors

WRIR 98-4100 provides depth-area reduction curves that are adapted from NOAA Atlas-2 (1973). These curves should be utilized to compute a basin-wide areal reduction factor for rainfall depth values derived from *WRIR 97-4004*.

5.2 PROBABLE MAXIMUM PRECIPITATION (NWS HMR 55A AND 57)

The National Oceanic and Atmospheric Administration (NOAA) conducted a nation-wide study of precipitation events mainly to address the need to develop data in support of the growing concern over dam safety issues in the late 1970's. Because of the potentially catastrophic results of dam failures, NOAA developed methods to estimate rainfall events that potentially create the most severe precipitation possible, given optimum meteorological conditions. These storms are defined as probable maximum precipitation, or PMP, events. NOAA conducted PMP studies for specific regions throughout the United States. The PMP studies are called Hydrometeorological Reports, or HMR's. Two HMR's cover the state of Montana: HMR No. 55A (1988), which was developed for the area of the United States between the Continental Divide and the 103rd Meridian (the longitudinal line just east of the Montana-North Dakota border); and HMR No. 57 (1994), which is for the Pacific Northwest States of Idaho, Oregon, Montana and Washington between the Continental Divide and the Cascade Mountains.

5.2.1 Storm Duration

PMP estimates were developed for both short duration ("local") and long duration ("general") events. General storms are defined as a major synoptic weather features that are longer than 6 hours duration and can cover large drainage areas. Local storms are generally shorter than 6 hours in duration (often only 1 or 2 hours long), are separate from general storm patterns, and are confined to smaller drainage areas. Local storms are often related to thunderstorm events.

HMR procedures typically apply to general storms having durations between 1 and 72 hours over areas between 10 and 10,000 square miles, and local storms having durations between ¼ and 6 hours over areas between 1 and 500 square miles. NOAA recommends

that for drainage areas less than 500 square miles, both the general and local storms should be considered.

The goal of estimating IDF for dams is to determine the worst case, or most conservative, scenario if options are available for a given storm event. In general, local storms will produce higher peak discharges and less runoff volume than general storms. Therefore, professional judgment may be needed to determine if a local storm or a general storm will produce the largest routed flood for spillway capacity analysis. Many times both storms need to be routed to determine which is the most severe. Often, spillways for reservoirs on small drainages will experience higher outflows from local storms than from general storms. The opposite is often the case with spillways on reservoirs with large upstream drainage areas. There are exceptions, however, and the user is cautioned to explore all plausible cases because other factors play a role in determining the worst-case scenario for spillway analysis, such as reservoir volume, dam height and drainage basin characteristics

5.2.2 Storm Depth Determination

Each HMR contains step procedures and examples for determining total and incremental depths for a specified storm. Time increments are determined by total storm duration, with shorter increments associated with shorter durations. There are some steps that require user decisions, such as the use of all-season or seasonal PMP estimates, depending on the application. The user is responsible for understanding the appropriateness of such factors.

Other factors in the step procedures will affect the calculated storm depth, such as areal reduction factors that are used to account for spatial variability of storms over larger drainage areas.

5.2.3 Temporal Distribution

HMR publications provide guidance on determining the sequential order of PMP increments. The sequence combinations provided are options for the user to determine the critical distribution for a specific drainage.

Another option is to use the temporal distributions found in *WRIR 98-4100* (described in Section 5.1.2 of this technical note), which are specific to Montana regional extreme storms. Options for determining sequences that fit with the intended purpose of the storm synthesis can allow the user flexibility in computing conservative hyetographs for dam safety purposes.

5.2.4 Areal Distribution

Procedures for areal distribution of the PMP over a basin are only provided for western Montana in HMR No. 57 for local, short-duration storms. If this method is used, the user can then eliminate rainfall adjustments for duration and basin area.

No other specific areal distribution procedures are given in HMR publications for Montana.

Use of areal distributions in a hydrologic model such as HEC-HMS requires special considerations on how the model is set up and developed. For synthetically produced precipitation, the HEC-HMS model distributes rainfall uniformly over the area of an identified subbasin. Areally distributed rainfall can be simulated by use of gage weights, gridded precipitation data or treatment of rainfall on specifically delineated subbasins within the entire drainage area.

5.2.5 Areal Reduction Factors

Both HMR 55A and HMR 57 provide depth area reduction curves which should be utilized to adjust PMP depths based upon total basin area.

5.3 DESIGN PRECIPITATION DEPTH

In Section 2.2 of this Technical Note, descriptions were given of how to compute an IDF for spillway capacity analysis. In general, the size of the IDF is dependent on the LOL downstream of the dam. For LOL less than and equal to 5, the IDF is computed by precipitation based on occurrence probability. For LOL equal to or greater than 1000, the IDF is computed by precipitation based on full PMP estimates. However, it is the case where LOL is between 5 and 1000 that computation of precipitation for the IDF becomes more complicated. The equation for calculating these precipitation depths are given in Section 2.2.2.2.

Provided in this section are three suggested methods for calculating precipitation depths for LOL between 5 and 1000: 1) The Non Areal Reduced Approximate Method, 2) The Areal Reduced Approximate Method and 3) The Incremental Precipitation method.

The Non Areal Reduced Approximate Method for calculating precipitation depths for LOL between 5 and 1000 is as follows:

1. Through previous analyses, determine the storm duration that produces the most severe routed spillway flow from an IDF. If this has not been done, then the steps that follow should be repeated, once for a short duration storm (usually no greater than 6 hours) and again for a long duration storm (usually 24 hours or longer).
2. At the selected storm duration, determine total precipitation depths for two events:
    a. A 5,000-year event using the references and procedures given in Section 5.1 of this Technical Note, without including the aerial reduction factor.
    b. A full PMP event using the references and procedures given in Section 5.2 of this Technical Note, without including the areal reduction factor.
3. Use the equation for Section 2.2.2.2 to compute an interpolated depth. Note that the areal reduction factors in WRIR 97-4004 differ from those utilized for development of the PMP. Leaving the areal reduction factors out of the 5,000

year and PMP precipitation values, avoids combining apples and oranges, so to speak. Note that the interpolated depth is not areally reduced.

4. Use procedures in WRIR 98-4100 (Section 5.2 of this Technical Note) to distribute the interpolated precipitation depth temporally. An areal reduction factor is applied at this time.

The Areal Reduced Approximate Method for calculating precipitation depths for LOL between 5 and 1000 is as follows:

1. Through previous analyses, determine the storm duration that produces the most severe routed spillway flow from an IDF. If this has not been done, then the steps that follow should be repeated, once for a short duration storm (usually no greater than 6 hours) and again for a long duration storm (usually 24 hours or longer).
2. At the selected storm duration, determine total precipitation depths for two events:
    a. A 5,000-year event using the references and procedures given in Section 5.1 of this Technical Note, including the aerial reduction factor.
    b. A full PMP event using the references and procedures given in Section 5.2 of this Technical Note, including the aerial reduction factor.
3. Use the equation for Section 2.2.2.2 to compute an interpolated depth. Since both the 5000 year storm and the PMP are aerial reduced, the interpolated depth is considered to be areally reduced.
4. Use procedures in WRIR 98-4100 (Section 5.2 of this Technical Note) to distribute the interpolated precipitation depth temporally. Since the precipitation is already areal reduced, the areal reduction factor is neglected (assigned a value of 1).

The Incremental Precipitation Method for calculating precipitation depths for LOL between 5 and 1000 is more technically accurate, but significantly more complicated than either Approximate Method. The procedure is as follows:

1. Develop areally reduced depth-duration curves for both the 5,000 year event and the PMP following the procedures given in WRIR 97-4004 and the appropriate HMR, respectively. Note that the areal reduction factors in WRIR 97-4004 differ from those utilized for development of the PMP. The reduction factors will also differ for each incremental duration.
2. Use the equation from Section 2.2.2.2 to compute an interpolated cumulative depth for each duration in the two depth-duration curves. The resulting interpolated depth-duration curve will be the design depth-duration curve.
3. Use procedures in *WRIR 98-4100* to develop a temporal distribution of incremental precipitation depths from the design depth-duration curve.

6.0 RESERVOIR AND SPILLWAY CHARACTERISTICS

Characteristics of the reservoir and spillway are important to identify the reservoir storage volume and spillway outflow characteristics for routing the IDF. Unless the reservoir has a relatively small volume in relation to the upstream drainage area, the reservoir pool is typically effective, at least to a certain degree, attenuating the peak discharge of the inflow design hydrograph. The extent of attenuation is also dependent on the required spillway IDF magnitude.

The term "spillway" in this section refers to a reservoir's principal and auxiliary spillways which are designed to safely convey flood waters past the dam. The capacity of the low-level outlet should typically be ignored in the flood-routing analysis since it is typically much smaller than the spillway capacity. Additionally, flood events often occur unexpectedly and may impair access to the dam, thus making it difficult to operate the gates. There are cases, however, where analysis of the outlet capacity is necessary and methods to assist in determining its stage-discharge relationship are given below.

6.1 RESERVOIR STAGE-AREA/VOLUME

One of the most difficult data features to obtain, the reservoir volume is often approximated unless a recent detailed bathymetric survey has been completed. Often the only reservoir volume information is from original design data, which may be outdated because of sedimentation in the reservoir. However, original design data may be the only reasonable information available. The user may need to exercise judgment or use other available data to determine actual reservoir volume.

As an alternative to existing volume data, there are two relatively easy methods to approximate reservoir volume. The first is to estimate volume using the simplified equation found in ARM 36.14.102, which is

Reservoir volume = 0.4 times the vertical height in feet from the downstream toe of the dam to the crest of the dam times the water surface area at that level in acres.

The above equation more closely approximates volume if the reservoir is fairly circular in surface area.

Another relatively simple method for reservoirs in natural basins is to approximate volume by interpolating an elevation-area relationship of the basin above the normal storage level for the reservoir. This can usually be accomplished with USGS 7.5 minute quadrangle topographic maps. The method involves the following steps:

1. Determine the area for several elevation contours above the normal water level of the reservoir. Assume the dam's location does not change.
2. Plot the contour elevations versus area on graph paper or using a spreadsheet graphing feature.
3. Also plot the elevation of the reservoir outlet, or known low point of the reservoir, at the zero area point.
4. Interpolate the line through the elevation zone of the reservoir, from the normal water surface elevation to zero, using the same shaped curve as for the plotted points, or by using a fitted-curve function of a spreadsheet.
5. Use the interpolated points to calculate volume by the elevation-area method.

6.2 DAM CREST ELEVATION AND WIDTH

The elevation of the low point on the dam crest and the width of the crest can be measured easily in the field, if the information is not already published. It is important to obtain the low-point elevation of the crest to understand when overtopping might occur. The crest width can be used to estimate flow over the dam if overtopping occurs during model routing. Overtopping flow can be approximated by appropriate broad-crested weir equations.

6.3 OUTLET CONDUIT DISCHARGE

For a conservative method of determining the spillway capacity, ignore the low-level outlet flow contribution during flood routing. For most small to medium sized earthen dams, the outlet capacity is much smaller than the spillway capacity, and it is reasonable to ignore outlet flow contribution. This is particularly true since it should not be assumed that the dam operators will be able to access the dam in a timely fashion during an extreme flood event.

6.3.1 Discharge Estimation

Three HEC-HMS methods can be used to estimate elevation-discharge relationships for the outlet if it is used in flood routing. The first method is to choose the 'Outflow Curve' option and calculate the elevation-discharge curve using established hydraulic equations. In HEC-HMS, the outflow curve can be entered as a paired data function. Calculated flow through a gated outlet with a pipe culvert should include the following:

- Discharges at several reservoir levels, accounting for the hydrostatic head above the outlet pipe
- Entrance and exit head losses and any head loss through gates
- Friction loss in the outlet pipe, accounting for pipe length, material on the inside of the pipe, the pipe's age and its condition
- Tailwater levels in the downstream outlet channel for the range of possible discharges

The second method available in HEC-HMS is to choose the 'Outflow Structures' option, which allows the model to compute outlet flow given a standard set of parameters. There are two methods available: orifice and culvert outlets. The orifice method applies to outlets without a culvert pipe, while the culvert method is used for low-level outlets where friction head loss would affect the outflow characteristics. The outflow structures option also computes emergency spillway flow, which is discussed in Section 6.4.

The third method is identified as 'Specified Release' in HEC-HMS. This option is used if actual outflow data has been measured and the gage information is used instead of an outflow curve. The measured flow is entered as a time-series gage and should represent actual measured outflows for time periods in the past and estimated outflows for any time periods in the future.

6.4 SPILLWAY STAGE-DISCHARGE

In most cases, the spillway is used only during runoff events. Also, spillways are typically open channels with relatively prismatic cross sections, or weir structures that have various crest configurations (such as broad-crested or ogee).

As discussed in Section 6.3 for outlets, HEC-HMS offers three ways to defined emergency spillway outflow characteristics: outflow curve; outflow structures; or specified release.

An 'Outflow Curve' is determined by independent calculation of spillway discharge for a range of reservoir elevations. Commonly, this is accomplished by use of a surface water profile model, such as HEC-RAS. Other methods to calculate the open-channel flow is by manual calculations using Manning's equation or by programmed software, such as FlowMaster® (Bentley, 2005), which can estimate flow in prismatic channels. The elevation-discharge or storage-discharge relationship is entered as a paired-data file.

The 'Outflow Structures' option has three methods available for calculating spillway discharges: broad-crested spillway; ogee spillway; or a specified spillway. Broad-crested and ogee methods will prompt the user to input parameters that define the chosen spillway. The specified spillway method is the same as entering an outflow curve, as described in the above paragraph, as a paired-data file.

'Specified Release' is essentially the same as described for principal spillway outlets in Section 6.3, except that flow data is measured for the emergency spillway. The measured data is entered as a time-series gage in HEC-HMS.

7.0 MODELING SURFACE RUNOFF AND FLOOD ROUTING

As indicated previously in this technical note, the most common runoff and flood routing model currently in use is HEC-HMS. While some of its limitations have been pointed out, HEC-HMS is relatively user-friendly and provides reliable results. The model is versatile in being able to route floods through reservoirs and spillways. It is a useful tool for dam safety evaluations to effectively determine spillway adequacy.

HEC-HMS is made available to the public at no cost. However, the Corps of Engineers does not provided technical support to the public and it is up to the user to understand the applicability and limitations of the model. The user is also responsible for upgrading the model as new versions become available.

In this section, we have provided a brief overview on how HEC-HMS is organized and important features that are needed to conduct a spillway capacity analysis. This is not a replacement for the HEC-HMS User's Manual or Technical Reference Manual and the user is responsible for becoming familiar with the program and its use.

7.1 HEC-HMS PROCEDURES

HEC-HMS is separated into components that contain data for use in the model. The components are:

Basin Model	Time-Series Data
Meteorological Model	Paired Data
Control Specifications	Grid Data

The Basin Model is shown graphically and allows the user to place icons for each basin component in the order of flow. Once data is entered into the model, the user prompts the model to perform computations that estimate runoff and routing. Results of the computations are available in tabular or graphical form.

Model features are described below.

7.1.1 Basin Model

All basin, subbasin, channel (or reach, as defined in HEC-HMS), and reservoir information are entered into the Basin Model. Options are also available for junctions on more complex basins, diversions, sources and sinks. The Basin Model is organized with the parameters shown in Table 7-1. Typical information for entering data for spillway capacity models is contained in Sections 3.0, 4.0 and 6.0 of this technical note. Each feature within the basin is connected in order of flow direction. Separate subbasins can be connected at confluence points with the Junction feature in HEC-HMS. There are also options to model diversions, water inflow sources and sinks where no outflow occurs.

7.1.2 Meteorological Model

All rainfall, snowmelt and evapotranspiration information are entered into the Meteorological Model. The Meteorological Model is organized with the parameters shown in Table 7-2. Typical information for entering meteorological data for spillway capacity models is contained in Section 5.0 of this technical note.

7.1.3 Control Specifications

The Control Specifications allow the user to specify the time period of the model. The user is asked to enter a starting date and time and an ending date and time, as well as a model time interval. The time interval usually corresponds to the interval used in time series data, such as precipitation or discharge gages.

TABLE 7-1. BASIN MODEL PARAMETERS FOR HEC-HMS

Component	Method	Parameter
Subbasin	Loss Method	Green and Ampt
		Gridded Deficit Constant
		Gridded SCS Curve Number
		Gridded Soil Moisture Accounting
		Initial and Constant
		SCS Curve Number
		Smith Parlange
		Soil Moisture Accounting
	Transform Method	Clark Unit Hydrograph
		Kinematic Wave
		ModClark
		SCS Unit Hydrograph
		Snyder Unit Hydrograph
		User-Specified S-graph
		User-Specified Unit Hydrograph
	Baseflow Method	Bounded Recession
		Constant Monthly
		Linear Reservoir
		Nonlinear Boussinesq
		Recession
Reach (Channel Routing)	Routing Method	Kinematic Wave
		Lag
		Modified Puls
		Muskingum
		Muskingum-Cunge
		Straddle Stagger
	Loss/Gain Method	Constant
		Percolation
Reservoir	Outflow Method	Outflow Curve
		Outflow Structures
		Specified Release
	Storage Method	Elevation-Area-Discharge
		Elevation-Storage-Discharge
Junction		
Diversion	Type	Inflow Function
		Lateral Weir
		Pump Station
Source	Type	Constant Flow
		Discharge Gage
Sink		

TABLE 7-2. METEOROLOGICAL MODEL PARAMETERS FOR HEC-HMS

Component	Method
Precipitation	Frequency Storm
	Gage Weights
	Gridded Precipitation
	Inverse Distance
	SCS Storm
	Specified Hyetograph
	Standard Project Storm
Evapotranspiration	Gridded Priestley-Taylor
	Monthly Average
	Priestley-Taylor
Snowmelt	Gridded Temperature Index
	Temperature Index

7.1.4 Time Series Data

Time series data includes the following type of information:

Precipitation Gages

Discharge Gages

Stage Gages

Temperature Gages

Solar Radiation Gages

Crop Coefficient Gages

Snow water Equivalent Gages

Time series data is information that includes time as a variable. Precipitation is usually the only type of time series data used in spillway analyses unless snowmelt is considered, in which case temperature, solar radiation and snow water equivalent gages may also be included.

7.1.5 Paired Data

Paired data are tables of information that identify relationships or functions between two variables for use in runoff and routing models. Options for paired data include:

Storage-Discharge Functions
Elevation-Discharge Functions
Elevation-Storage Functions
Elevation-Area Functions
Cross Sections
Inflow-Diversion Functions
Diameter-Percentage Functions
Unit hydrograph Curves
Percentage Curves
ATI-Meltrate Functions
ATI-Coldrate Functions
Groundmelt Patterns
Meltrate Patterns

Elevation, storage and discharge data are normally associated with reservoirs and spillways. Cross sections are used in channel routing methods. Most of the remaining paired data could be used in spillway analyses if needed.

7.1.6 Grid Data

Grid data for runoff-routing model is based on data captured during a discrete time frame and utilizes radar-based estimates for simulation. Grid data provides actual spatial data over a basin, whereas other time series data assumes uniform areal distribution over a basin. Therefore, it can be useful for calibration of a specified storm, but data may be hard to obtain. The options for grid data include:

Precipitation Grids

Temperature Grids

Solar Radiation Grids

Crop Coefficient Grids

Storage Capacity Grids

Percolation Rate Grids

Storage Coefficient Grids

Moisture Deficit Grids

Impervious Area Grids

SCS Curve Number Grids

Elevation Grids

Cold Content Grids

Cold Content ATI Grids

Meltrate ATI Grids

Liquid Water Content Grids

Snow Water Equivalent Grids

7.1.7 Simulation Runs and Results

HEC-HMS allows the user to create and run simulations for specified subbasins and meteorological models. Features in HEC-HMS gives the user options to check data prior to computations and messages appear to give the user information about the simulation, such as warnings and errors. Once a run is successfully computed, the user can view a variety of tables and graphs that display the results of the simulation.

7.2 SUGGESTED PHASE APPROACH

Modeling flood routing for evaluating spillway capacity can be a detailed and complex effort. When the cost of conducting such a study is considered, it is a benefit to the user and potential clients to look at ways to expedite the evaluation process and to save time and money where possible. Therefore, in this section we offer suggestions on phasing the evaluation process as an approach to determine spillway adequacy.

If detailed information is available and building a reliable model is relatively easy, then it is always better to use the best available data. Sometimes introducing overly conservative data, such as assuming no infiltration of rainfall, is a way of determining if the spillway exceeds its required capacity and limiting the time to develop more a detailed model. However, this approach does not allow a reasonable estimate of the basin's reaction to rainfall nor does it provide an accurate estimate of the spillway's actual capacity.

The following are steps suggested for building a flood routing model in a phased approach:

- Develop the model with data needed to begin the evaluation process:
    - Reservoir and spillway elevation-storage-discharge paired data.
    - Rainfall/snowmelt time-series data for the required return interval. For dams with estimated large LOL downstream, if it is suspected that the reservoir will pass the PMF, it may be wise to look at the PMF first. If the reservoir passes the PMF, there is no need to estimate the LOL downstream or calculate the IDF.
    - Basic basin characteristics such as drainage area and transform (unit hydrograph) information.
- Make conservative assumptions first to check if spillway capacity is adequate.
    - Conservative assumptions include: reservoir storage that is smaller than actual; larger rainfall storm than required; smaller spillway size than actual, use of lag equation for routing subbasin flows down to reservoir; etc.
- Run the model with conservative soil/infiltration assumptions first and check spillway adequacy.
    - Assume no initial abstraction and little to no rainfall losses. Note that HEC-HMS will calculate initial abstraction when using NRCS Curve number method if an initial abstraction of zero is entered.
- If spillway does not pass the routed flow at each intermediate steps, build a more detailed model with more exact information.

8.0 MODEL VERIFICATION

Any hydrologic model is as "good", or accurate, as the information input to the model. It is crucial to modeling that some form of verification be conducted to assure the model is as accurate as possible. In dam safety, the consequences of inaccurate modeling can be long-lasting and even severe. Underestimating spillway size may have the unfortunate result of dam failure, which can be devastating for the owner, engineer, and the public downstream. Overestimating spillway size is very costly to an owner. Putting effort into verifying the model may cost more in engineering analysis, but usually is a relatively small amount if done in a logical and professional manner, especially compared to the high cost of construction or the overwhelming cost of damages from failure.

This section provides guidance for conducting verification of hydrologic models used for spillway analyses. Actual hydrologic data may be scarce or difficult to obtain, but there are publications available that can assist the user in most cases.

8.1 MODEL UNCERTAINTY

In Montana, hydrologic records have been kept, at best, approximately one hundred years. Some data may have longer records and most are shorter. Streamflow gages exist on many waterways, but are more common on larger rivers. Most small streams are not gaged. Studies have been conducted by the USGS and other agencies that produced regression relationships to help predict flow frequency and magnitude on ungaged streams. While the regression equations developed for ungaged streams are reasonably accurate, they are based on gage data from regional streams, which have limited record lengths, usually no more than about one hundred years. So when spillway hydrologic analyses are conducted for runoff events that exceed a return interval of 500 years and greater the uncertainty associated with the flow estimates can be very significant.

Parameter estimates for basin characteristics tend to be general in nature, especially in larger basins, and are based on best available data or empirical relationships. Parameter selection,

such as soil and ground cover type, infiltration rates and unit hydrograph parameters each introduce uncertainty to the model.

The same is true for meteorological data, where gage data is likely not available for watersheds being considered, and where gage records, if available, are relatively short in length compared to the return intervals required for spillway analyses. User decisions for temporal and spatial distribution are subjective, though there are references for Montana that provide guidance based on statistical analyses of actual gage data. Regardless, rainfall and snowmelt input to a hydrologic model will invariably introduce additional uncertainty.

But any uncertainty introduced into a model is balanced against what should be considered reasonable, when using best available data. The methods included in this technical note provide references to data that are considered to be the best available for Montana. The goal of "reasonable" is reached when model verification is accomplished to within standard error bounds of recorded gage data or regression equations. Variability of model results will still exist among different users and according to differing objectives for specific spillway analyses, but hopefully the procedures for verification mentioned in this section will produce somewhat consistent methodologies.

8.2 MODEL CONSERVATISM

Because of uncertainty of a hydrologic model for spillway analysis, there is sometimes a common reaction for users to intentionally introduce conservatism as an assurance that the model will exceed standards and reduce risk of failure. Being conservative in spillway analyses is a choice that professionals must make depending on the dam, the risk of failure, and input from regulatory agencies, the public and the dam owner.

As briefly mentioned in Section 7.2, introducing overly conservative data as a first step in a phased approach to modeling is an option in determining if a spillway exceeds required capacity and it tends to reduce the time of analysis if the spillway successfully passes the conservative flood flow. This may be effective for only determining if the spillway "passes or fails" the simulated flow. But further analysis is necessary if the spillway does not

successfully pass the conservative flow, or if the analysis will be used to route multiple levels of storm magnitudes as part of the spillway analysis that would require verification that the storm estimates are reasonable.

Introducing conservative assumptions at various points in a hydrologic analysis make it difficult to verify model results. In Section 8.3, where model verification techniques are discussed, the goal is to verify, to the extent possible with available data, the results of the hydrologic model using peak flows established by statistical gage analyses or regional regression equations. If model input is knowingly conservative, verification will not be possible.

By virtue of the spillway standards set for high hazard dams in Montana, at least some conservatism is inherently introduced in the spillway analysis. Section 2.0 of this technical note provides an explanation of standards whereby spillway standards are established on the basis of LOL in the event of dam failure. An IDF is assigned a return interval of 1,000 times the expected LOL up to a 5,000 year return period. Between 5 and 20 LOL, the IDF is interpolated between the 5,000 year return period and the PMF. The PMF is the standard for LOL equal to or greater than 1,000. All of the IDF standards, including the minimum 500-year flood, are very large events established because of the catastrophic consequences, but whose occurrences are very rare. Adding conservatism to already rare events may make the analysis unreasonable, in addition to being unverifiable.

8.3 VERIFICATION METHODS

Because streamflow records are limited, statistical analyses to determine storm frequency peak flows can only estimate up to approximately 100-year, or possibly 500-year, return interval peaks. While these storm peaks may be relatively small in comparison to spillway design peaks, they still represent large, infrequent storms. The response of a Montana drainage basin to a 100- or 500-year rainfall event may be similar to that of a larger event, especially if soil infiltration rates reach the point of saturation and most of the rainfall becomes direct runoff. It is reasonable, then, to use 100- or 500-year peak streamflows to

verify hydrologic models for a spillway IDF. Smaller return intervals may be used for model verification if no other data exists.

In this section, we will discuss methods to conduct verification (sometimes called "pseudo-calibration") of hydrologic models using peak flows developed from streamflow gage data or USGS regression equations for ungaged basins. Adjustment of the model to match estimated peaks usually requires modification of basin characteristics. More specifically, it is common to adjust model parameters such as the unit hydrograph and basin losses so that the modeled peak flows match or exceed peak streamflow estimates from USGS regression equations or flood-frequency analyses. This also means that appropriate return interval rainfall to match the streamflow return interval peaks will need to be input to the model. This is contrary to the concept that rainfall of a specified return period will not always produce peak runoff of the same return period, but it is the closest method available.

8.3.1 Model Parameters

The primary model parameters that may be utilized to pseudo-calibrate the runoff peaks from the model are those associated with the unit hydrograph and basin losses. Although both will affect the runoff peak, changes made to the basin losses will also affect the runoff volume. It is generally more conservative to calibrate by adjusting the unit hydrograph since this will only affect the runoff peak without affecting the total runoff volume.

Unit Hydrograph Parameters: Tc and R (Clark Unit Hydrograph) and tp and qp (Dimensionless Unit Hydrograph) should be estimated using the equations given in *WSP 2420* (Section 3.2.2.1). These two parameters may be utilized to pseudo-calibrate the model, but should remain within one standard deviation of the estimated value.

Basin Infiltration Parameters: The parameters available to pseudo-calibrate the model are the "percent impervious area", "initial abstractions", and the loss rate (typically the curve number or ultimate infiltration rate). Each of these parameters has a range of "reasonable" values that may be estimated utilizing published guidelines (Section 3.3). The model should

be run with various combinations of basin infiltration parameters during the process of verification.

8.3.2 Gage Data

If the drainage basin upstream of a reservoir considered for spillway analysis has one or more streamflow gages near the reservoir or nearby in the basin, the recorded data could be used to determine a desired return period peak flow by a direct frequency analysis or analysis by transposition.

Probably the most common distribution used to conduct a frequency analysis of streamflow gage data is Log Pearson Type III. This distribution has been found to fit well with streamflow data and has wide application in hydrologic studies. Use of Log Pearson Type III analysis was popularized with the publication of Bulletin 17B (USGS, 1981) by the Interagency Advisory Committee on Water Data. Methods developed in Bulletin 17B have become the standard for conducting streamflow frequency analyses. The user can follow Bulletin 17B methods to conduct frequency analyses on streamflow data sets of at least 10 years. It is desirable to estimate flows to the highest return period possible in order to allow reasonable model verification for extreme floods.

Techniques for transposition of flows from a gage that is not located near the location of the reservoir but within the drainage basin being considered can be found other hydrologic technical references.

8.3.3 USGS Regression Equations (USGS WRIR 03-4308)

Approximately every ten years, the USGS publishes an updated version of regression equations that estimate flood frequency for ungaged streams. The latest publication is Water-Resources Investigations Report (WRIR) 03-4308 (2004) which is based on water data through 1998. Regression equations were developed that relate frequency peak flows to various basin and climate characteristics, as well as to bankfull widths. Estimates can be calculated for return intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years.

Methods in WRIR 03-4308 are easy to implement and provide reasonable estimates of frequency flows when no gage data is available.

8.4 CONFIDENCE IN VERIFICATION AND MODEL CONSERVATISM

Since analysis of gage data and the use of regression equations have associated uncertainty, and "best estimates" for parameters have been utilized throughout the development of the model, it is necessary that the model be verified to insure that it's results are reasonable and that an appropriate level of conservatism is applied at this final step. The model results are typically considered to be "reasonably conservative" if they are within a confidence band between the calculated mean value and the mean value plus one standard deviation of the streamflow estimates (whether from gauged data or from the USGS regression equations). Additionally, it is important to verify that the model will continue to yield reasonably conservative results when it is used to estimate flows beyond the 500-year flood. This may best be accomplished by plotting the model results for the 100-year and 500-year peak inflows on the flood-frequency graph that contains the historic (or regression) streamflow estimates. The slope of the line between the 100-year and 500-year model result points should be equal to or greater than the slope between the corresponding streamflow estimate points. If the slope is too flat, it is very likely that the model will underestimate peak flows for larger events.

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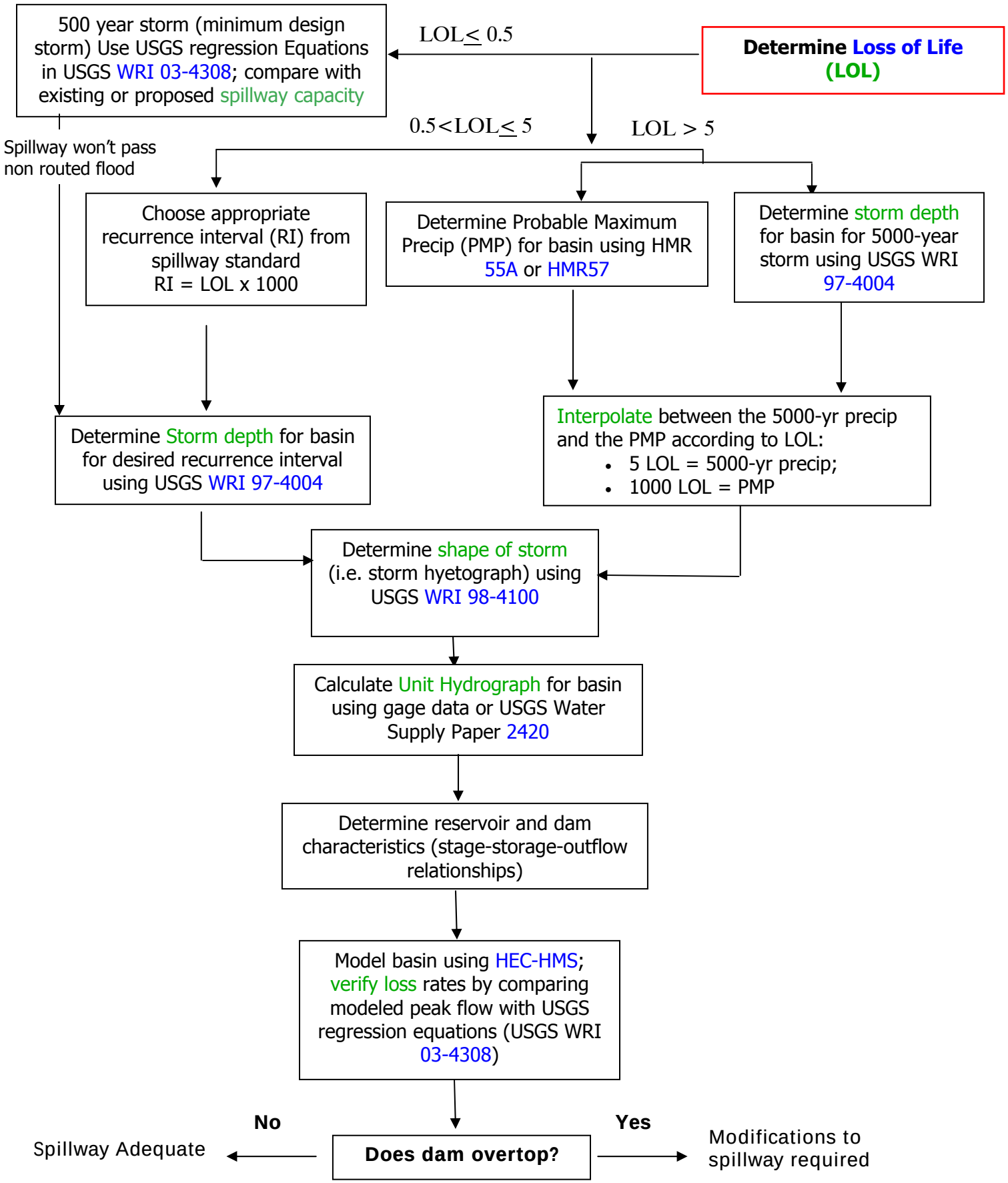
APPENDIX A

FLOWCHART PROCEDURE FOR DETERMINING COMPLIANCE WITH MONTANA SPILLWAY DESIGN STANDARDS

Procedure for Determining Spillway Adequacy



APPENDIX B

MINIMUM INFLOW DESIGN FLOOD FOR HIGH HAZARD DAMS (MONTANA SPILLWAY STANDARDS COMMITTEE TECHNICAL DECISIONS, MAY 1999)

MINIMUM INFLOW DESIGN FLOOD FOR HIGH HAZARD DAMS

MONTANA SPILLWAY STANDARDS COMMITTEE

TECHNICAL DECISIONS

May 1999

Introduction

Under current Montana Rule 36.14.502, the Probable Maximum Flood (PMF) or a fraction thereof is often used to calculate the inflow design flood for high hazard dams. It is required that the reservoir and spillway safely store and pass the design flood. Inflow design criteria are based on both reservoir volume and dam height. Some form of the PMF criteria are applied unless a reservoir is less than 100 acre-feet and the dam is less than 20 feet high.

Under the current rule, the required spillway size for existing dams is not related to potential loss of life downstream from the dam. For example, the criteria remains the same regardless if one loss of life or one hundred loss of life would result from spillway failure below a given dam.

A goal of the Montana Department of Natural Resources and Conservation (DNRC), Dam Safety Section, is to implement a hydrologic standard for spillways that is risk based, with dams having a large population below being held to a more stringent criteria than dams having a low population below. Therefore, during the spring of 1997, the Montana Spillway Standards Committee was formed to advise the Dam Safety Section in development of new rules for spillway conveyance requirements. The committee is made up of dam owners, downstream residents of dams, consulting engineers, and government employees. The purpose of this report is to document the recommendations made by this committee.

In support of this effort, the U.S. Geological Survey (USGS), with some financial assistance from DNRC, conducted a study to characterize extreme storms that have a very low probability of occurrence. As a result, we are now able to estimate precipitation depths, throughout Montana, with recurrence intervals as high as 5,000-years. After determination of rainfall depth, the resulting flood is routed through the reservoir to estimate required spillway size.

Discussed in this report are recommendations by the Montana Spillway Standards Committee regarding risk vs. recurrence interval for the design flood and loss of life assessment. This report only addresses spillway requirements and not hydrologic techniques or other structural aspects of dams. Hydrologic techniques used by DNRC to help assess the proposed spillway standards are presented in "Montana Spillway Standards - Hydrologic Analysis", DNRC, May 1999.

Risk vs. Recurrence Interval - Inflow Design Flood

B.C. Hydro has pioneered the development of quantified risk analysis for dam safety evaluations. B.C. Hydro owns and operates 61 dams and is responsible for the production and distribution of electrical energy for the province of British Columbia, Canada. B.C. Hydro has adopted a mathematical annual expected value of loss of life for each dam of 0.001.

The committee recommends that a probability value of .001 (0.1% annually) of loss of one life due to spillway failure is acceptable. The associated recurrence interval for annual probability of .001 is 1,000-year. Therefore, the estimated loss of life due to spillway failure is multiplied by 1,000 to determine the inflow design storm recurrence interval that must be routed in the reservoir and passed by the spillway. For example, if a spillway failure is estimated to result in the loss of 2.4 lives, the spillway and reservoir will need to route the 2,400-year recurrence interval rainfall to be considered safe. If the spillway just meets this criteria, there will be a .042% ({1/2400}x100) chance each year that the 2.4 lives will be lost, and during a 50 year period there will be a 2% ($1-\{1-.00042\}^{50}$) chance that these lives will be lost.

The committee found that once a loss of life can be estimated from spillway failure, an appropriate inflow design storm with an assigned recurrence interval or probability of occurrence must safely be stored in the reservoir and passed by the spillway.

Committee Suggested Criteria

If the estimated loss of life is greater than zero and less than or equal to 0.5, the committee determined that the spillway and reservoir must be able to store and pass the 500-year runoff event. In other words, the minimum standard inflow design flood for high hazard dams is the 500-year flood. A graphical display of spillway standards for five loss of life or less is shown in Figure 1.

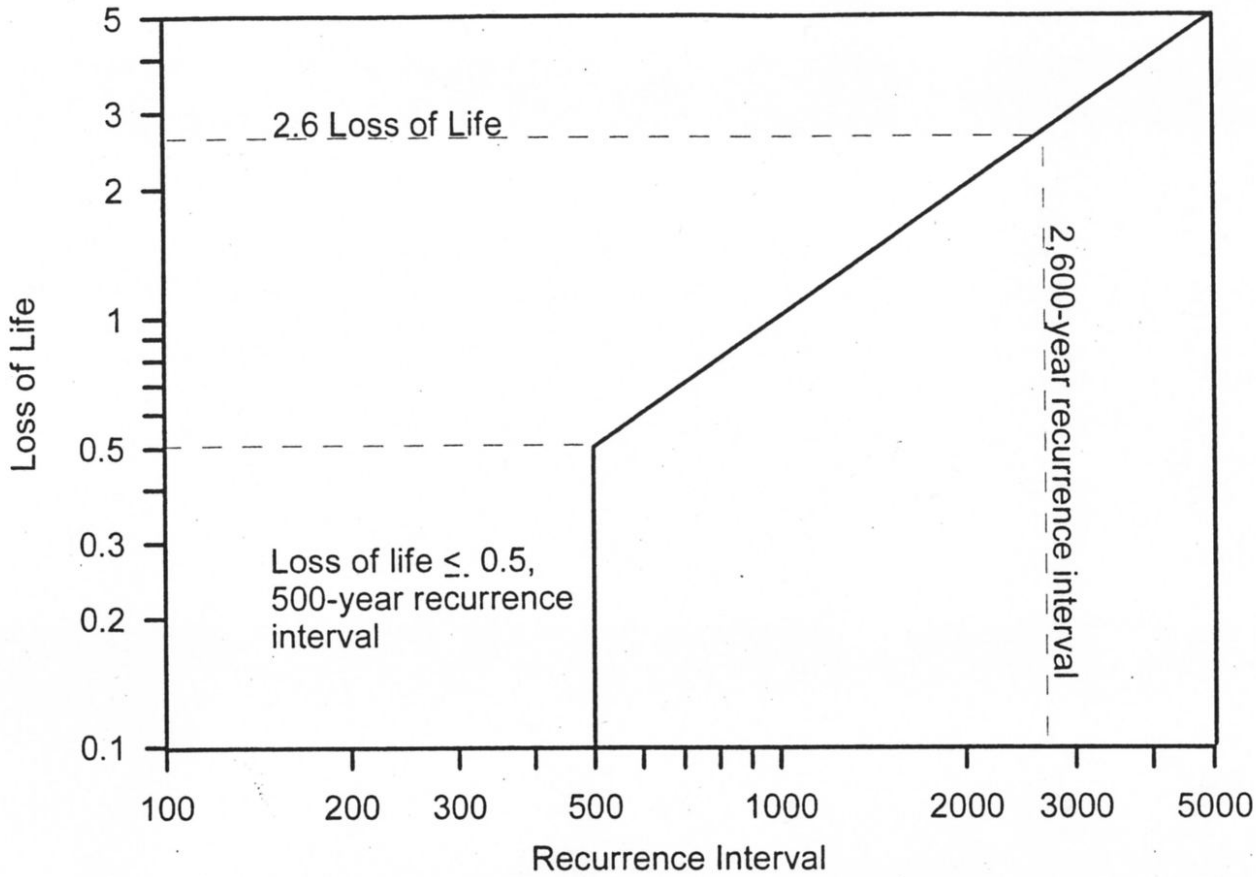


Figure 1. Minimum Standard Inflow Design Flood with an Estimated Loss of Life of Five or Less

If the loss of life is greater than 5, the probability-based approach will no longer be used and the inflow design flood is derived from the precipitation computed using equations 1 through 3. It needs to be emphasized that although no probability is associated with the standard above five loss of life, the standard does become more severe as expected loss of life increases below the dam. The results of the committee's decision on this portion of the standard are shown in Figure 2.

Eq. 1 $P_s = P_{5,000}\,(10^{d})$

Eq. 2 $r = -0.304 + .435 \log_{10}(lol)$

Eq. 3 $d = \log_{10}(PMP) - \log_{10}(P_{5,000})$

lol = loss of life (5< lol <1,000)

PMP = Probable Maximum Precipitation

$P_{5,000}$ *= 5,000-year recurrence interval precipitation*

P_s *= Design precipitation to meet spillway standard*

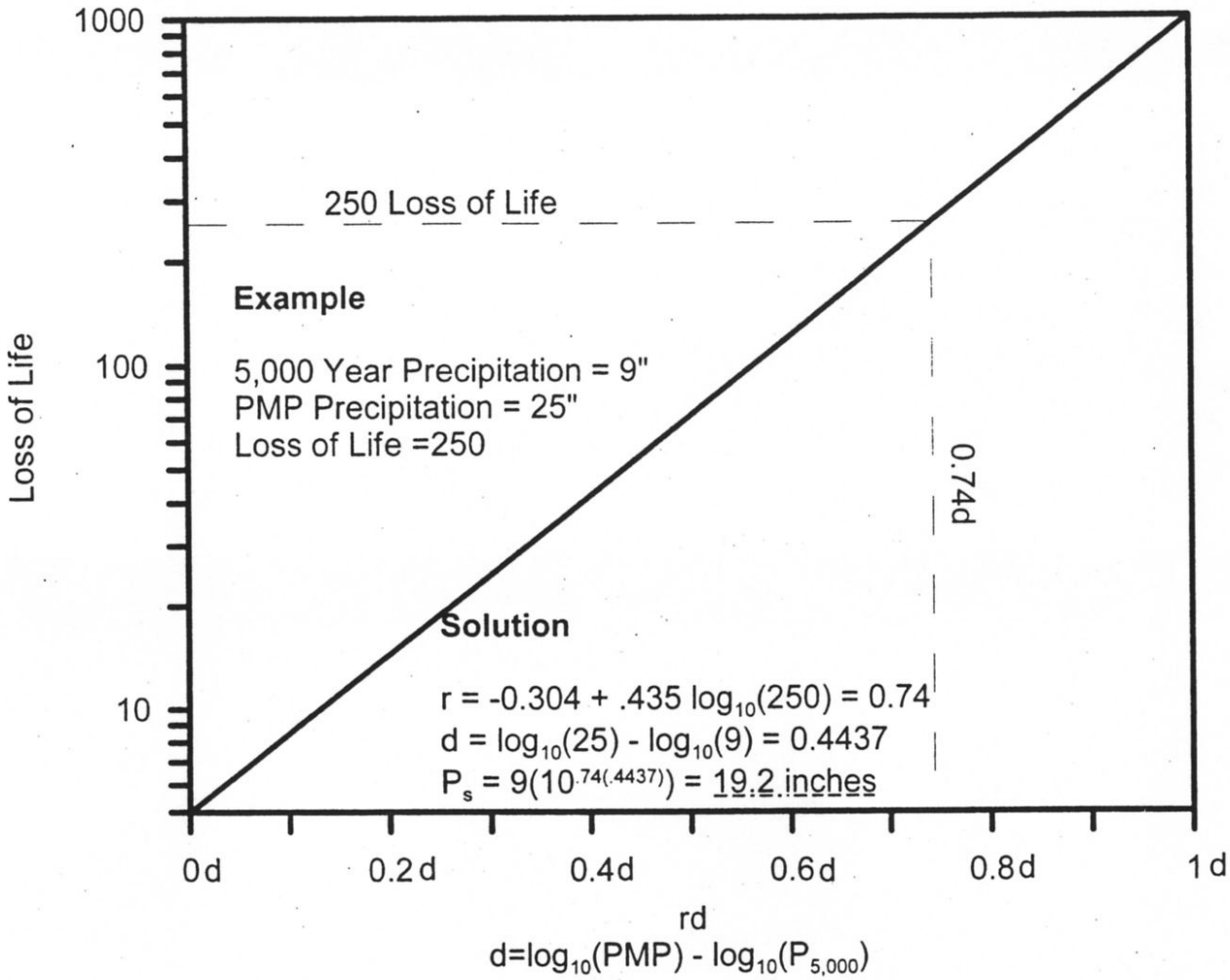


Figure 2. Minimum Standard Inflow Design Flood with an Estimated Loss of Life Between 5 and 1,000

The spillway standard changes for a loss of life greater than 5 not because the overall risk-based approach is no longer acceptable, but there is currently no acceptable way to estimate rainfalls with recurrence intervals greater than 5,000-year events.

For only the purposes of computing the risk factor, which will be discussed shortly, the PMP event is assumed a 1:1,000,000 event for interpolation.

If the loss of life is greater than or equal to 1,000, the reservoir and spillway must safely store and pass the runoff resulting from the PMP storm, often called the probable maximum flood or PMF.

Current design criteria provide for the minimum design storm to be reduced if it can be shown no further loss of life results from spillway failure. This criteria will be kept under the new standard.

Compliance of Existing Dams

For existing dams, the Montana Spillway Standards Committee has decided that it would be unreasonable to expect all existing spillways to come under compliance in a short period of time.

To assist the DNRC Dam Safety Section in prioritizing spillway construction or rehabilitation, the committee suggested using a risk factor developed using both the expected loss of life below the dam and the recurrence interval storm that the existing dam and spillway can safely store and pass. The risk factor is determined using Equation 4.

Eq. 4 $$RF = RI_{SW}/LOL$$

RF = *Risk Factor*

RI_{SW} = *Flood recurrence interval that the spillway can currently pass*

LOL = *Estimated loss of life associated with spillway failure*

If the RF value is 1,000 or above, the existing spillway meets or exceeds the standard and a larger spillway is not required. The committee has recommended for spillways significantly undersized (RF value below 100) that immediate action be taken. These actions may include reservoir level restrictions or breaching. These dams have a more than 1% probability each year of loss of life due to spillway failure.

For RF values between 100 and 500, proof of diligent effort towards correcting the problem will be required for issuance of operation permits.

For RF values between 500 and 1,000, dams will be evaluated on a case-by-case basis. The committee felt that these dams are sufficiently close to meeting the new standard, and the need for repair is not urgent if the spillway is in good condition.

Loss of Life Assessment

The committee examined several methods to estimate loss of life, caused by spillway

failure, downstream from a dam. Many methods base the loss of life (LOL) from the population at risk (PAR). They found the best current method to come from "Predicting Loss of Life in Case of Dam Failure and Flash Flood," Michael L. DeKay and Gary H. McClelland, Risk Analysis, Vol. 13, No. 2, 1993. In the future, new and better methods may become available. These methods should then be used.

The DeKay and McClelland method is based on an empirical approach that incorporates warning time, PAR, and the force of the flood. It is suggested by DeKay and McClelland that no one who is more than 3 hours travel time below the dam be included in the PAR. It is also strongly recommended that the PAR not be lumped into smaller reaches and zones of inundations since this leads to overestimates of LOL. The following equations are given by DeKay and McClelland to determine loss of life.

Eq. 5

$$LOL_{HF} = \frac{PAR_{HF}}{1 + 13.277(PAR_{HF}^{0.440})e^{(2.982(WT_{HF}) - 3.790)}}$$

Eq. 6

$$LOL_{LF} = \frac{PAR_{LF}}{1 + 13.277(PAR_{LF}^{0.440})e^{(0.759(WT_{LF})}}$$

LOL_{HF} = *Loss of Life in High Force Area*

LOL_{LF} = *Loss of Life in Low Force Area*

PAR_{HF} = *Population at Risk in High Force Area*

PAR_{LF} = *Population at Risk in Low Force Area*

WT_{HF} = *Warning time for High Force Area*

WT_{LF} = *Warning time for Low Force Area*

In most cases the committee recommends that 0 warning time be used. This assumption can be modified if sufficient evidence can be shown that a warning time exists.

The force of flood will often be estimated at site. In general, if the flood will occur in a narrow canyon area, the flood will likely be high force. If the area downstream of the dam is flat and wide, it is likely that much of the areas within the inundation zone will be classified low force.

If more specific information is needed regarding the flood force, the document "Downstream Hazard Classification Guidelines," ACER Technical Memorandum No. 11, U.S. Bureau of Reclamation, 1988 may be useful. Shown in Figures 3-5 are plots of velocity vs. depth for houses, mobile homes, and passenger vehicles. The various zones are high danger, low danger, and judgment.

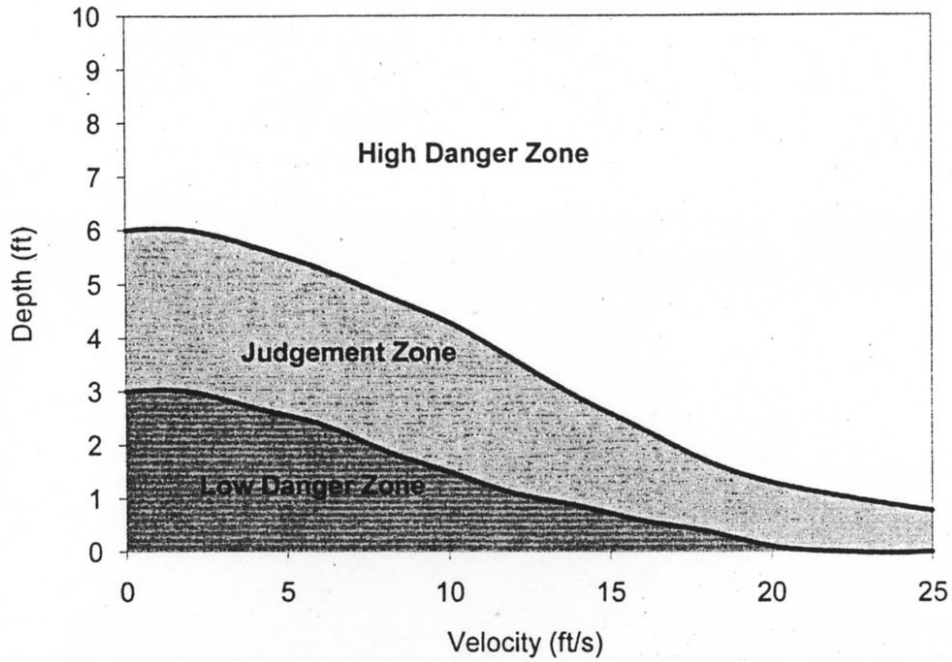


Figure 3. - Depth-Velocity Flood Danger Level Relationships for Houses Built on Foundations

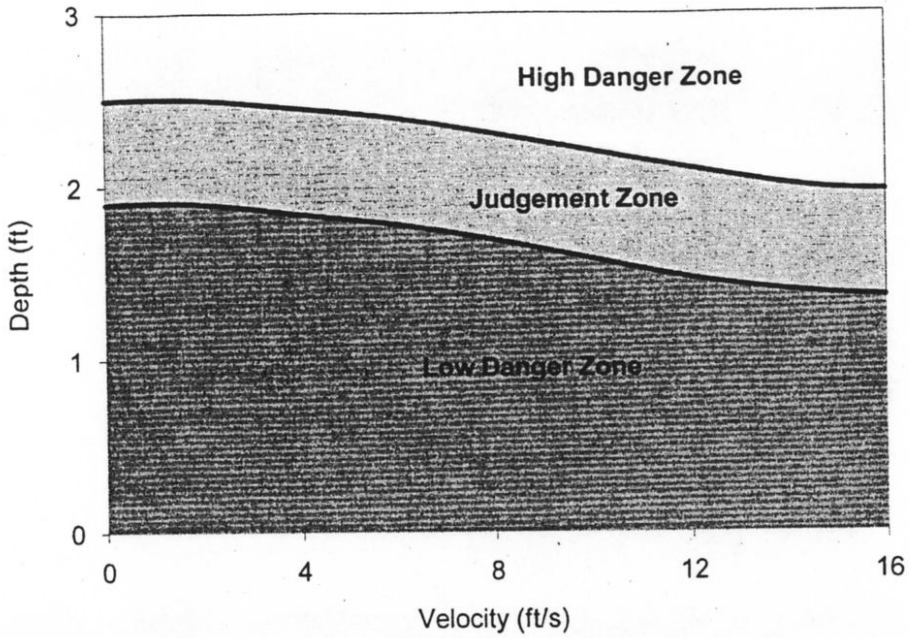


Figure 4. - Depth-Velocity Flood Danger Level Relationship for Mobile Homes

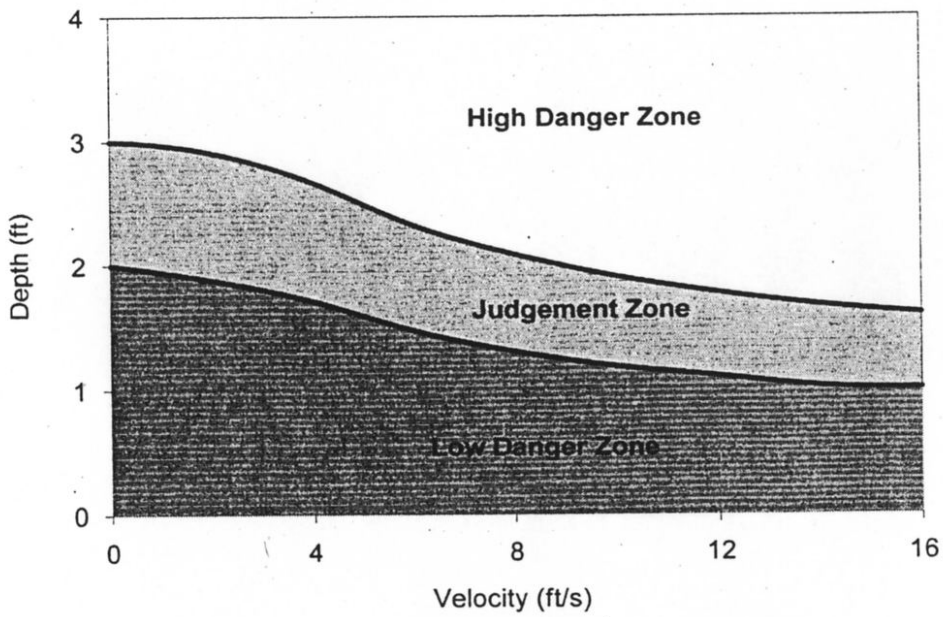


Figure 5. - Depth-Velocity Flood Danger Relationships for Passenger Vehicles

The estimation of PAR in the high force area and the subsequent use of the high force equation has the most significant effect on the LOL. Special attention will be focused on defining the area influenced by the high force wave and the PAR in the area.

Conclusion

The design precipitation used to determine spillway size under the proposed rule is very different from the design precipitation used under the current rule. The proposed rule requires the design precipitation to be based on population level downstream of the dam whereas the current rule requires the design precipitation to be based on the height and volume of water associated with the dam.

Since the population at risk is closely related to whether the force of water is high or low after dam failure, the proposed rule does still indirectly incorporate height of dam within the criteria. The current rule only considers that some population is at risk below the dam. The level of population at risk plays a small to nonexistent role in the spillway conveyance criteria.

For these reasons, dams with large populations at risk downstream, will often have more stringent spillway requirements under the proposed rules. On the other hand, dams with small populations at risk will often have less stringent spillway requirements under the proposed rules. The Montana Spillway Standards Committee has decided that the risk of life downstream should be the overriding factor in determining spillway capacity.

APPENDIX C

NRCS CURVE NUMBER TABLES FROM CHAPTER 9 HYDROLOGIC – SOIL COVER COMPLEXES OF THE NRCS NATIONAL ENGINEERING HANDBOOK, TITLE 210

Table 9.1.--Runoff curve numbers for hydrologic soil-cover complexes

(Antecedent moisture condition II, and $I_a = 0.2\ S$)

Land use	Cover: Treatment or practice	Cover: Hydrologic condition	Hydrologic soil group A	B	C	D
Fallow	Straight row	----	77	86	91	94
Row crops	"	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	"and terraced	Poor	66	74	80	82
	" " "	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	"and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes 1/ or rotation meadow	Straight row	Poor	66	77	85	89
	" "	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	"	Good	55	69	78	83
	"and terraced	Poor	63	73	80	83
	"and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	"	Fair	25	59	75	83
	"	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		----	59	74	82	86
Roads (dirt) 2/		----	72	82	87	89
(hard surface) 2/		---	74	84	90	92

1/ Close-drilled or broadcast.
2/ Including right-of-way.