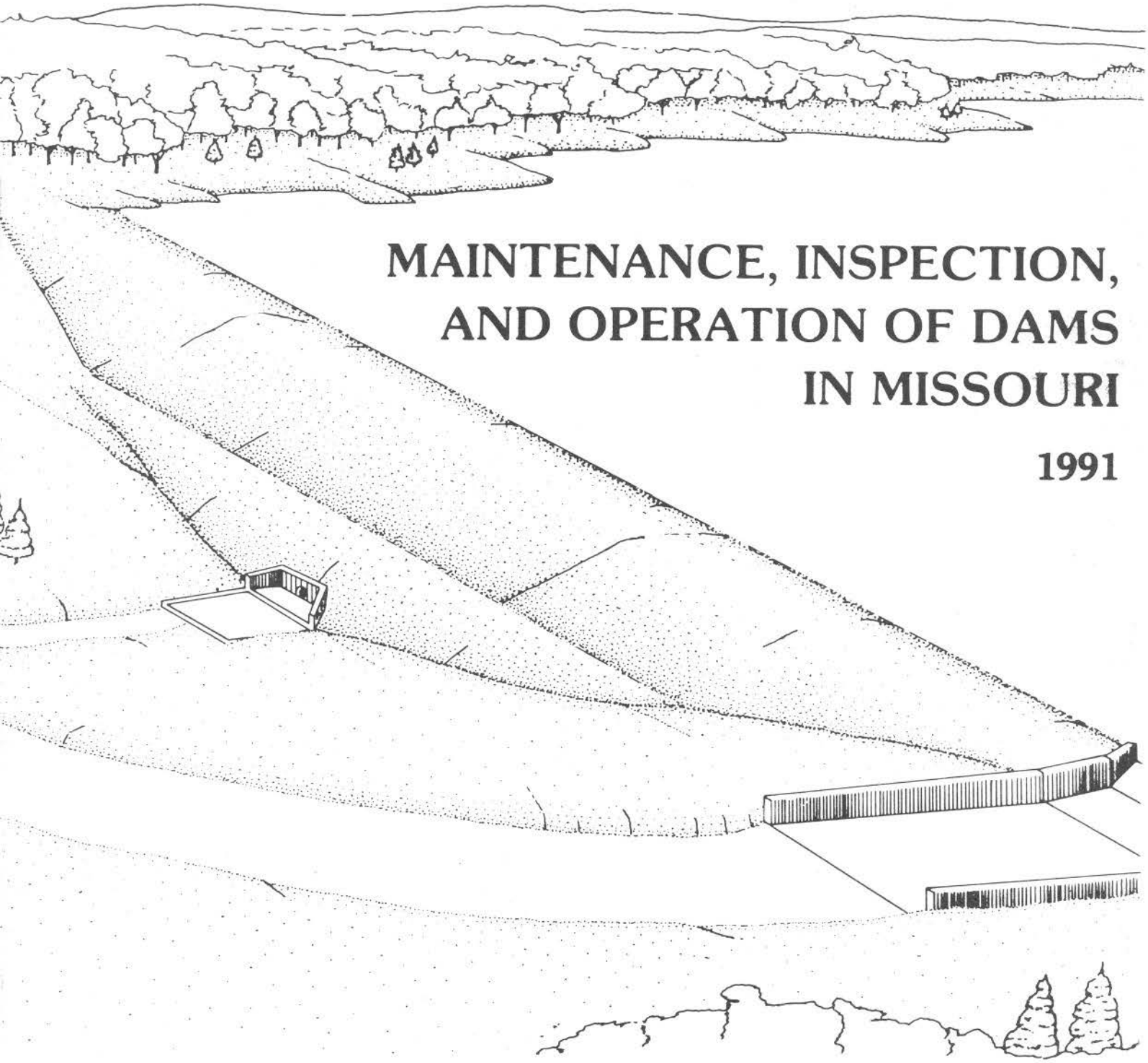

MAINTENANCE, INSPECTION, AND OPERATION OF DAMS IN MISSOURI

1991

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

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MAINTENANCE, INSPECTION, AND OPERATION OF DAMS IN MISSOURI

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for the

MISSOURI DAM AND RESERVOIR SAFETY COUNCIL

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PREFACE

This manual was developed to help owners of dams establish a program of maintenance, operation, and visual inspection activities. Emphasis has been placed on small earth structures, although some information has been supplied on other types of dams commonly found in Missouri: concrete gravity dams, concrete arch dams, rock fill dams, lead tailings dams, and barite tailings dams. The primary objective of any maintenance and operation plan should be to detect observable defects and avert a potential disaster.

This manual is not intended as a design guide for remedial measures, but as a source of information which the owner can use in his regular maintenance and inspection activities. Throughout this booklet, there are numerous recommendations to contact an engineer experienced with dams when certain observations are made. The importance of these recommendations cannot be over emphasized. Dams are complex structures and the causes and remedies of certain problems may not be obvious to a lay person.

Certain information in this manual was taken in part from existing publications. Thanks are extended to the Geological Survey Program of the Division of Geology and Land Survey, Missouri Department of Natural Resources as well as the Ohio Department of Natural Resources for the use of their existing operation and maintenance manuals.

This manual was first published in 1986. Several changes have been made and included in this second edition. Experience gained from the inspection of several hundred dams has lead to revisions in the chapters on Maintenance and Operation of dams.

TABLE OF CONTENTS

		PAGE
I	INTRODUCTION	1
II	EMERGENCY ACTIONS	2
	A. Types of Failures	2
	B. Emergency Actions and Procedures	4
III	DAM SAFETY LAWS	8
IV	LIABILITY AND RESPONSIBILITIES OF DAM OWNERS	9
	A. Potential Liability for Dam Owners	9
	B. Environmental Concerns	10
	C. Insurance	10
V	INSPECTIONS	11
	A. General	11
	B. Owner Inspection	11
	C. Engineer Inspections	11
	D. Guidelines on Hiring Engineers	13
	E. Design Modifications	14
VI	MAINTENANCE	15
	A. Spillways	15
	1. Emergency Spillway	15
	2. Principal Spillway Conduits	16
	3. Trashracks	19
	4. Concrete Repair	19
	B. Seepage	21
	C. Embankment Cracks and Slides	24
	D. Erosion	26
	E. Vegetation	29
	F. Burrowing Animals	32
	G. Reservoir	34
	H. Monitoring Devices	34
	I. Tailings Dams	35
VII	OPERATION	39
	A. Operation Plans	39
	B. Reservoir Levels	39
	C. Lake Drains	40
	D. Mechanical Equipment	41
	E. Sedimentation and Dredging	41
	F. Vandalism	42
	G. Record Keeping	43
	H. Checklists	44
	GLOSSARY	51
	REFERENCES	55

I. INTRODUCTION

How important is maintenance? If designed and constructed properly, should not all dams be maintenance free? The answers to these questions may seem obvious, but several small dams in Missouri fail every year due to the lack of timely maintenance. In most cases, failure could have been prevented if these "structures" had been properly maintained. Dams must not be thought of as part of the natural landscape, but as man-made structures which must be designed, inspected, operated, and maintained accordingly. Maintenance is an ongoing process that not only involves such routine items as mowing the grass and clearing the trashrack, but also includes regularly inspecting the structure and properly operating its components.

Major rehabilitation of a dam should not be necessary if the dam was designed in accordance with good engineering practice, was built using good construction standards and is operated and maintained properly. Engineers generally agree that the design of a dam is not complete until after the dam has been built and the reservoir has filled with water. Design engineers should perform field inspections periodically after construction to ensure that the dam is constructed properly.

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. However, this objective cannot be accomplished without the continued cooperation of owners, operators, engineers, and contractors. This manual was developed to assist owners in their regular maintenance, operation and inspection activities. Many of the ideas for this manual came from owners. The information provided herein is intended to help owners maintain safe dams.

In this manual the word dam refers to any artificial or man-made barrier which does or may impound water. A dam may be composed of timber, rock, concrete, earth, steel, mill tailings, or a combination of these materials. Associated works include spillways, and water supply facilities, and lake drain structures. Most dams in Missouri have an earth embankment and one or two spillways.

Figure 1 - Overview of an earth dam

II. EMERGENCY ACTIONS

TYPES OF FAILURES

Earth Dam Failures

Owners of dams and operating and maintenance personnel must be knowledgeable of the potential problems which can lead to failure of a dam. These people regularly view the structure and, therefore, need to be able to recognize potential problems so that failure can be avoided. If a problem is noted early enough, an engineer experienced in dam design, construction, and inspection can be contacted to recommend corrective measures, and such measures can be implemented. IF THERE IS ANY QUESTION AS TO THE SERIOUSNESS OF AN OBSERVATION, AN ENGINEER EXPERIENCED WITH DAMS SHOULD BE CONTACTED. Acting promptly may avoid possible dam failure and the resulting catastrophic effect on downstream areas.

The booklet "Dam and Reservoir Guidelines for Community and County Emergency Action Planning" is available from the Dam and Reservoir Safety Program (address listed below). These guidelines will assist the owner in preparing an Emergency Action Plan (EAP)

Engineers from the Department of Natural Resources, Dam and Reservoir Safety Program are available at any time to inspect a dam if a serious problem is detected or if failure may be imminent. Contact the following:

Missouri Dept. of Natural Resources
Division of Geology & Land Survey
Dam and Reservoir Safety Program
P.O. Box 250
Rolla, Missouri 65401

Phone: 314/368-2175 (during business hours) or State Emergency Management Agency - phone: 314/751-9773 (during business hours) 314/751-2748 (emergency)

Because only superficial inspections of a dam can usually be made, it is imperative that owners and maintenance personnel be aware of the prominent types of failure and their telltale signs. Earth dam failures can be grouped into three general categories. These are: overtopping, seepage, and structural failures. A brief discussion of each type follows.

Overtopping Failures

Overtopping failures result from the erosive action of water on the embankment. Erosion is due to uncontrolled flow of water over, around, and adjacent to the dam. Earth embankments are not designed to be overtopped and therefore are particularly susceptible to erosion. Once erosion has begun during overtopping, it is almost impossible to stop. A well vegetated earth embankment may withstand limited overtopping if its top is level and water flows over the top and down the face as an evenly distributed sheet without becoming concentrated. The owner should closely monitor the reservoir pool level during severe storms.

Seepage Failures

All earth dams have seepage resulting from water percolating slowly through the dam and its foundation. Seepage must be controlled in both velocity and quantity. If uncontrolled, it can progressively erode soil from the embankment or its foundation, resulting in rapid failure of the dam. Erosion of the soil begins at the downstream side of the embankment, either in the dam proper or the

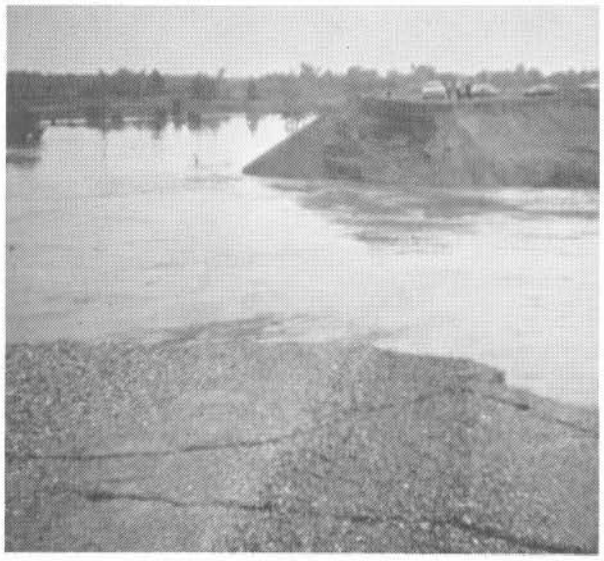

Figure 2 - Dam breach in progress

foundation, progressively works toward the reservoir, and eventually develops a "pipe" or direct conduit to the reservoir. This phenomenon is known as "piping". Piping is usually caused by uncontrolled seepage and initially it cannot be detected by visual inspections. Piping can continue for years at a very slow rate or it can develop quickly depending upon the type of soil in the dam and the hydraulic gradient of the seepage water. When it is well developed, piping is characterized by an increased seepage flow rate, the discharge of muddy or discolored water, sinkholes on or near the embankment, and a whirlpool in the reservoir. Once a whirlpool (eddy) is observed on the reservoir surface, complete failure of the dam will probably follow in a matter of minutes. As with overtopping, fully developed piping is virtually impossible to control and will likely cause failure.

Structural Failures

Structural failures can occur in either the embankment or the appurtenances. Structural failure of a spillway, lake drain or other appurtenance may lead to failure of the embankment. Cracking, settlement, and slides are the more common signs of structural failure of embankments. Large cracks in either an appurtenance or the embankment, significant settlement, and major slides will require emergency measures to ensure safety, especially if these problems occur suddenly. When any of these conditions are observed, the appropriate authorities should be notified (see page 2) and professional advice should be sought. The owner may also consider lowering the lake level until repairs can be made.

Figure 3 - Seepage through embankment

Figure 4 - Erosion of spillwaydischarge channel

The three types of failures previously described are often interrelated in a complex manner. For example, uncontrolled seepage may weaken the soil and lead to a structural failure. A structural failure may shorten the seepage path and lead to a piping failure. Surface erosion may result in structural failure.

Minor defects such as cracks in the embankment may be the first visual sign of a major problem which could lead to failure of the structure. The seriousness of all deficiencies should be evaluated by someone experienced in dam design and construction. A qualified professional engineer can recommend appropriate permanent remedial measures.

The next section on Emergency Actions and Procedures includes information on what to do in the event that a serious problem is detected or failure of the dam appears imminent. Also described are temporary actions and repairs which can be initiated if any of the three types of failure are identified.

EMERGENCY ACTIONS AND PROCEDURES

Dam owners and operating personnel must be prepared to act promptly and effectively when a dam begins to show signs of failure. Early identification of a hazardous situation may provide additional time to warn and evacuate downstream residents and to implement measures to prevent or delay dam failure. Because failure of a dam may take only minutes or hours, it is imperative to have a detailed plan of action ready for use. The emergency plan should include procedures for notification and coordination with local law enforcement and other governmental agencies, information on potential area of inundation, plans for warning and evacuation, and information on resources and procedures for making emergency repairs.

Identification of Emergency Conditions

Early identification of hazardous conditions at a dam will allow prompt implementation of emergency actions and procedures. Dam owners and operators should be familiar with the principal types of failure and their telltale signs as described in this section on Earth Dam Failures. If any of the following conditions are noted, the emergency plan should be implemented **immediately.**

Figure 5 - Slide scarp

1) *The dam is overtopping or nearly overtopping.* The dam owner or operator should closely monitor the level of the reservoir during periods of heavy rainfall and runoff. If the spillway and reservoir storage capacities are exceeded, overtopping will occur. Overtopping can result if a large slide in the upstream or downstream slope of the embankment significantly lowers the dam crest. Blockage of pipe spillways may also cause overtopping of a dam.

2) *Piping (internal erosion of soil from the dam or its foundation) has developed.* Piping is usually indicated by a rapid increase in seepage rate, a muddy discharge at or near the downstream toe, sinkholes on or near the embankment, and/or a whirlpool (eddy) in the reservoir. Boils at or near the downstream toe may be indications that piping is beginning.

3) *A large slide develops in either the upstream or downstream slope of the embankment and threatens to release the impounded water.*

4) *Sudden and rapid failure of an appurtenant structure threatens complete failure of the dam and release of its impoundment.*

Identification of any of these conditions at a dam should be cause for alarm and the emergency plan should be implemented promptly. If there is a question as to the severity or urgency of the suspected problem, contact the Dam and Reservoir Safety Program at (314) 368-2175 during business hours or the State Emergency Management Agency duty officer at (314) 751-9773.

Response to and Notification of Emergency Conditions (Emergency Action Plan)

The response to an identified emergency situation should proceed in three steps. First, the owner or person who identifies the emergency should notify local law enforcement officials and those persons residing immediately downstream from the dam. Law enforcement and local officials should then proceed with warning and evacuation procedures for potentially affected areas. Second, the owner or operator should notify the Dam and Reservoir Safety Program of the emergency. Third, after notifying local law enforcement and state dam safety officials, the owner

should initiate efforts to prevent or delay the failure. This sequence of actions is summarized as follows:

Owner/Observer

1) Notify local officials and warn residents living immediately downstream from the dam.
2) Implement actions to prevent or delay failure.
3) Notify the Dam and Reservoir Safety Program.
4) Contact an experienced professional engineer.

Local Officials

1) Determine affected area.
2) Contact the State Emergency Management Agency.
3) Implement warning/evacuation plan.

Notification

The first step in developing an Emergency Action Plan for a dam is for the owner to establish a list of agencies/persons to be contacted. Input for this list should be obtained from and coordinated with local law enforcement officials and county disaster assistance personnel. The following agencies can offer emergency assistance in the event failure of the dam appears imminent.

1) Local sheriff, police, and/or fire departments
2) County Disaster Services Personnel
3) County Engineer
4) Missouri Dept. of Natural Resources
   Dam and Reservoir Safety Program
   P.O. Box 250
   Rolla, Missouri 65401
   (314) 368-2175

A copy of the notification list should be posted in a prominent, readily accessible location at the dam near a telephone and/or radio transmitter, if possible. This list should be periodically (once or twice a year) verified and updated as necessary. The list should include individual names and titles, locations, office and home telephone numbers, and radio frequencies and call signals as appropriate. Special procedures should be developed for nighttime, holiday, and weekend notification and for notification during a severe storm when telephones may not be working or highways may be impassable.

The notification plan should be brief, simple, and easy to implement under any set of emergency conditions.

Warning and Evacuation Plans

Certain key elements of information must be included in every warning and evacuation plan. Information about potential inundation (flooding) areas and travel times for the breach (flood) wave is essential to the development and implementation of these emergency plans. Inundation maps showing potential areas of flooding as a result of dam failure are especially useful. More detailed information about how to identify inundation areas and the development of mapping of potential flood areas is available from the Dam and Reservoir Safety Program.

At the present time, very few inundation maps are available for local officials to use in their emergency warning and evacuation plans. Consequently, local officials and dam owners will have to use common sense in determining necessary areas of evacuation. Areas nearest to the dam must be evacuated first. Flood Hazard Boundary maps can provide rough approximations of necessary evacuation areas. However, the evacuation area should be extended beyond the limits of the maximum flood area shown on these maps as floods resulting from dam failures are usually more widespread and destructive. In making these determinations, it is always better to err on the conservative side.

Whenever possible, warning of a dam failure or an impending dam failure should follow procedures already established for other emergencies. However, it must be stressed that warning and evacuation times will be limited and that immediate evacuation must follow. Warnings delivered through personal modes such as telephones, loud-speakers, and face-to-face communications are more effective than warnings delivered impersonally - by sirens for example. Persons delivering the warnings should always say "the dam is failing", and not "flooding is expected." Warnings should be clear and concise. Residents should be advised to move to safety **immediately**. Radio and television news

media should be used to the extent available and appropriate. Residents are more likely to respond if they receive warnings from several sources.

Resources and Procedures For Making Emergency Repairs

After making appropriate notifications of a possible dam failure and implementing warning/evacuation procedures, the owner should initiate efforts to prevent or delay failure of the dam. Because of the likely limitation on time, it is important to identify in the emergency plan the location of available resources with which to attempt to avoid (delay or prevent) the failure. Any emergency repair will require equipment, materials, labor, and expertise. For large reservoirs where failure could result in loss of life or severe damage to high-value property, materials (clay, sand, gravel, stone, riprap, sandbags, cement, plastic sheeting, etc.) and equipment for handling these materials should be kept at the site. If this provision is not possible, then prior arrangements for use of locally available off-site materials and equipment should be made in case of emergency. A list of contractors and other labor sources should be maintained.

It is also important to know what types of emergency repairs should be attempted for the different modes of failure. The following descriptions of possible actions to take to avoid failure are offered. Caution must be exercised by those working around the dam during the implementation of any of these emergency measures.

Overtopping of Embankment

If overtopping appears imminent, the following actions should be taken:

1) Notify local authorities and state dam safety officials of possible failure.

2) Be sure that the spillways are not plugged with debris and are functioning as efficiently as possible. Debris removal may be difficult due to pressure from the high velocity flow and should be accomplished by using long poles or hooks. Personnel should **not** be allowed close to spillway inlets.

Figure 6 - Breached dam

3) Open all lake drains or other gates to lower the pool level. Pumps and/or siphons may also be helpful on small reservoirs.

4) Dig a by-pass channel around the dam through an abutment. The location for this channel should be chosen with extreme caution so that the embankment will not be affected by rapid erosion of the channel. This action should **not** be undertaken without the supervision of an experienced professional engineer. The owner should realize that downstream flooding may increase as a result of this action.

Generally, it is not recommended that the top of the embankment be temporarily raised with sandbags or by other means to try to prevent overtopping during a severe storm. This action is dangerous because the flood inflow may increase and result in the overtopping of the raised dam. If the temporarily raised dam fails, the release of an even greater volume and depth of water will result.

Piping

If piping has developed the following actions should be taken:

1) Notify local authorities and state dam safety officials of possible failure.

Figure 7 - Piping failure

2) Open all lake drains and other gates to lower the pool level. Pumps and/or siphons may also be helpful on small reservoirs.

3) Attempt to plug the "pipe" at the upstream end by dumping material into the whirlpool or sinkhole. Straw has been used effectively for this purpose. If straw is not readily available, other materials (earth, rock, etc.) should be tried. If the "pipe" is plugged, the owner should be aware that this is only a temporary repair. The reservoir should be fully drained and a professional engineer should be contacted to recommend permanent remedial measures.

Structural Failure of Embankment or Appurtenances

If piping has developed the following actions should be taken:

1) Notify local authorities and state dam safety officials of possible failure.

2) Open all lake drains and other gates to lower the pool level. Pumps and/or siphons may be helpful on small reservoirs.

3) Attempt emergency repairs to prevent or delay failure.

4) Contact an experienced professional engineer.

Slides may be caused by seepage pressures, a saturated slope, a slope which is too steep, or possibly an earthquake. Earthquakes can cause structural damage to the embankment or appurtenances which might lead to complete failure of the dam. If a large slide in the upstream or downstream slope has occurred which significantly lowers the dam crest and threatens to release impounded water, sandbags can be used to temporarily raise the crest to prevent overtopping. On large reservoirs, beaching and rapid erosion of the upstream slope by wave action could occur due to high winds. A complete breach of the dam crest may result if the slope protection fails and bare soil is exposed to wave action.

Temporary repair of appurtenant structures will depend on the nature of the problem.

Once again, extreme caution should be exercised by those working around the dam during emergency conditions when there is uncontrolled flow of water. Some of the measures which can be taken to prevent failure of the dam could result in an increase of flooding downstream.

Owners should not allow temporary actions to become permanent repairs. This practice is dangerous because the chance of a rapid and catastrophic failure may increase if the repairs are not adequate. A qualified professional engineer should be contacted to recommend appropriate permanent remedial measures. Before any permanent repairs are made, the Dam and Reservoir Safety Program should be contacted.

III. DAM SAFETY LAWS

Missouri law, Chapter 236.400-236.500; RSMo, (1986) requires that a construction permit application be made to construct new dams or modify, remove, or alter existing dams. In addition, owners of existing dams 35 feet or more in height must obtain a registration permit and owners of new dams 35 feet or more in height must obtain a safety permit after construction to operate the structures. All regulated dams must be inspected periodically to assure that their continued operation and use does not constitute a hazard to public safety, life and property. Dams less than 35 feet in height are not subject to the permit and inspection requirements. See 10 CSR 22-1.020(24) for the method used to measure the height of a dam. The Missouri Department of Natural Resources, Dam and Reservoir Safety Program is responsible for administration of the dam safety law in Missouri.

Although there are approximately 3,900 inventoried dams in the state, only about 600 are regulated under Missouri law.

Before the first registration permit can be obtained by an owner, a registered professional engineer experienced in the design, construction, and operation of dams must perform an inspection of the dam. Owners may request that the inspection be performed by a registered professional engineer on the staff of the Dam and Reservoir Safety Program or they may retain a private professional engineer. After the inspection, a report must be prepared, complete with engineering calculations, a list of deficiencies, and a permit application. Reference is made to 10 CSR 22-3.030 which explains the registration permit process in detail. The staff of the Dam and Reservoir Safety Program reinspects each dam at the time the permit is renewed which is usually every 5 years.

The National Dam Safety Act (Public Law 92-367) was passed by Congress in 1972. It called for an inventory of dams in the United States and a one-time inspection of those dams that would result in loss of life in the event of failure. In Missouri, 607 dams were inspected under this federal program which ended in 1981. Copies of these reports are kept on file by the Dam and Reservoir Safety Program staff.

Owners of dams should be aware that they are legally responsible for the operation, maintenance, and inspection of their structures. Negligence by owners in fulfilling their responsibilities can lead to the creation of extremely hazardous conditions to downstream residents and properties.

Failure of a dam can result in loss of life, considerable loss of capital investment, loss of income, and property damage. Loss of the reservoir can cause hardship for those dependent on it for their livelihood or water supply and will upset the ecological balance of the area. In the event of failure, the owner can be subject to a barrage of liability claims and possibly even criminal charges.

If a failure occurs during a severe flood, it is likely that downstream residents will blame their damage on the dam failure even though it may have contributed only a small portion of water to the flood. It is very difficult, if not impossible, to prove in court that the failure had little or no effect on the downstream area during passage of the flood. Consequently, dam owners are often held liable for downstream damages.

Understanding and recognition of potentially dangerous conditions may prevent catastrophic dam failure. It appears that the majority of deficiencies in the proper maintenance of dams occur because the owners do not have an understanding of the techniques necessary for a proper program of maintenance and inspection.

Figure 8 - Overview - earth dam and spillway

IV. LIABILITY AND RESPONSIBILITIES OF DAM OWNERS

POTENTIAL LIABILITY FOR DAM OWNERS

Dam ownership carries with it significant legal responsibilities. The dam owner should be aware of the potential liabilities and how to conscientiously deal with these liabilities.

This section only attempts to make dam owners aware of potential liability and is not an attempt to give legal advice. Furthermore, some areas of the law regarding dam ownership and liability are uncertain or have not been decided by Missouri courts. Please keep in mind that the general rule may not be followed in a Missouri court. Dam owners and operators should obtain competent legal counsel when dealing with legal issues of dam ownership.

A dam owner should first be familiar with the legal obligation to maintain a dam in a safe and reasonable condition. The **general rule** is that a dam owner is responsible for its safety. Liability can be imposed upon a dam owner for failure to maintain, repair or operate the dam in a safe and proper manner. This liability can apply not only to the dam owner, but also to any company that leases the land upon which the dam sets, or any person who operates or maintains the dam. If an unsafe condition existed prior to ownership of the dam, the new dam owner may be absolved of liability should the dam fail during his term of ownership. Thus, the new owner must carefully inspect the structural integrity of the dam prior to purchase and then provide inspection, maintenance and repair thereafter.

Because the dam owner is responsible for dam safety, it is important to note what must be done to comply with that legal duty. The dam owner must do what is necessary to avoid injuring persons or property. This usually applies to circumstances and situations which can be anticipated. A dam owner would generally not be responsible for those circumstances that a reasonable person could not anticipate. One key action is almost universally recognized: In order to meet the responsibility of maintaining a dam in a reasonable and safe condition, virtually every jurisdiction will require a dam owner to conduct regular inspections of the dam and maintain and/or repair deficient items. Regular inspections by qualified professionals are virtually mandated if a dam owner is to identify all problems and correct them.

In addition to liability problems arising out of dam ownership, operation of the dam is also a significant legal issue. First and foremost is the simple right to operate. State law requires a permit to construct, repair and/or operate a dam that is 35 feet or more in height. In addition, a dam on a navigable stream may involve federal government regulations which may govern operation.

Beyond the basic permitting question, all dam owners must consider the effect of dam operation on the rights of other water users, whether they are upstream or downstream from the facility. For both upstream and downstream users, this responsibility includes a duty to avoid negligent flooding of their property.

A general rule in some states is that the dam owner must protect downstream land owners from additional flooding, if those downstream owners have come to rely on the existence and operation of the dam to reduce flooding. The dam owner is therefore advised to consider dam operations in the light of the downstream land owners' expectations and dependency on the dam to prevent flooding.

In situations where there is no specific duty to protect downstream owners from flooding, the dam owner must still operate the dam conscientiously. Dam owners must be in a position to clearly show that their dam did not increase flooding.

Upstream users may also have the right to be protected from damage caused by operation of the dam. Therefore, the dam owner is advised to assess the legal as well as the physical impact of **any** change in the level of the impoundment, including dam removal.

Dam owners must remember that they are ultimately liable for the safety of their dams.

This section on liability is only a general introduction to the many issues regarding dam owner liability. The discussion is intended to provide a basis for the owner to

consider liability potentials and to encourage the dam owner to seek competent legal counsel and/or technical experts to help resolve any problems that exist at a dam. Where the ownership and operation of dams and impoundments are concerned, the old saying, "an ounce of prevention is worth a pound of cure" is truly appropriate.

ENVIRONMENTAL CONCERNS

While there are an infinite number of potential environmental issues, a few basic areas of concern should be addressed before a dam is purchased or its method of operation altered.

Dams with gates for regulating the impoundment and downstream flow can cause water levels to fluctuate. These fluctuations can cause gain or loss of wetland habitat affecting fish spawning, waterfowl and shorebird nesting. Fluctuations of water levels can also increase shore erosion, cause unsafe ice conditions and affect the stability of the embankment.

Variations in the impoundment and downstream elevations can impact fish in the impoundment or the river. Evaluation of existing fisheries and the impact of changes will require consultation with the Missouri Department of Conservation.

Within a dam impoundment, it is likely that sediment will accumulate over the years. This is especially true for dams in western and northern Missouri. Release of these sediments downstream by dredging, operation of the dam, changing the impoundment level or removing the dam could result in significant damage and liability to the dam owner. In addition, release of sediments downstream could adversely impact plant and wildlife for significant time periods. It is also quite common for the sediments to contain pollutants. Thus, the dam owner should carefully consider the possible impacts of dam operation and how it affects the environment.

INSURANCE

The primary goal of dam insurance is to share the risk and protect the assets and financial well being of the dam owner. Insurance cannot make a dam safe, or make an inherently faulty structure or renovation project into a good one. Inadequate coverages or insufficient limits on those coverages, coupled with a major loss, can mean the financial ruin of a dam owner. In order to obtain insurance and get a reasonable rate, the dam owner will have to show that the dam meets all state standards with regard to design, construction, and operation.

When insuring a dam, the owner should employ a competent insurance agent or broker as early as possible. Whenever a dam requires modification, reconstruction, or renovation, any agent or broker involved will be very interested in the adequacy of the dam owner's insurance program.

The primary job of the agent is to serve as a contact point between the client and the insurance companies, and to place the insurance coverage with appropriate companies. The agent, depending on his skill, dedication, and relationship with insurance markets, can greatly affect both the premiums quoted by the companies and the availability of certain coverages. Although most types of insurance have standard contract forms, many of the details of the coverage are open to negotiation and can be tailored to meet the needs of the dam owner, except in those areas mandated by law. It is important for the dam owner to work with his agent to define conditions of the policy that are of real importance and those that need modification.

V. INSPECTIONS

GENERAL

The purpose of a dam inspection program is to identify observable defects and unsafe conditions. Inspections may be conducted either by the dam owner or an engineer; however, frequent inspections are the most important part of an owner's maintenance and operation plan. Once defects have been identified, it is imperative that steps be taken to repair the dam immediately. Failure to correct identified maintenance and repair items leads to deterioration of the dam which could threaten public safety, life or property. Therefore, it is important for the owner to know how to visually inspect his dam and when to have an engineer look at the structure.

An inspection program for a dam starts during construction and continues on a regular basis throughout the life of the dam. A dam is an active structure, constructed of materials that are subject to erosion, corrosion, and deterioration by wind, water, ice and temperature. Water passing over, under and through a dam exposes it to continuing deterioration and possible weakening of the structural elements. A well documented inspection program will observe this deterioration and identify needed repairs and maintenance items that, if carried out, can prevent structural failure of the dam.

OWNER INSPECTIONS

Owner inspections are carried on throughout the life of the structure and include frequent visual inspections and recording of data from instrumentation at the site. To conduct an owner's inspection, the dam owner should be familiar with the type and parts of the dam and with the words commonly used to describe them. The Glossary located in the back of this booklet should help the owner understand these terms.

The inspection of earth, concrete, and tailings dams by the owner should include a visual observation of the spillway and outlet works, mechanical equipment, earth embankments, abutment areas, concrete structures, operating equipment, and appurtenant works. The area downstream of the toe of the dam should be inspected to detect seepage emerging from the foundation beneath the embankment. A specific description of each of these items is contained in the chapter on Maintenance. If seepage monitoring devices such as v-notch weirs are present, the flow rate and temperature of the seepage should be measured and kept on record. In many cases, measurements of daily rainfall totals, reservoir elevations, spillway flows, and piezometric readings can also be made by the owner. The owner is encouraged to keep accurate records and write down any additional observations that he believes are important. Sample checklists have been included in the chapter on Operation to help with record keeping.

ENGINEER INSPECTIONS

A dam inspection by a qualified registered professional engineer provides a thorough, systematic evaluation of the condition of the dam. To obtain the initial registration permit for Missouri dams constructed prior to August 13, 1981, the owner is required to have a registered professional engineer inspect his dam in accordance with the Missouri Dam and Reservoir Safety Council Regulations. The purpose of the inspection is to evaluate the safety of the dam and to insure that the dam meets certain basic minimum safety standards. The engineering inspection often requires special equipment and should be

Figure 9 - Field inspection of spillway inlet

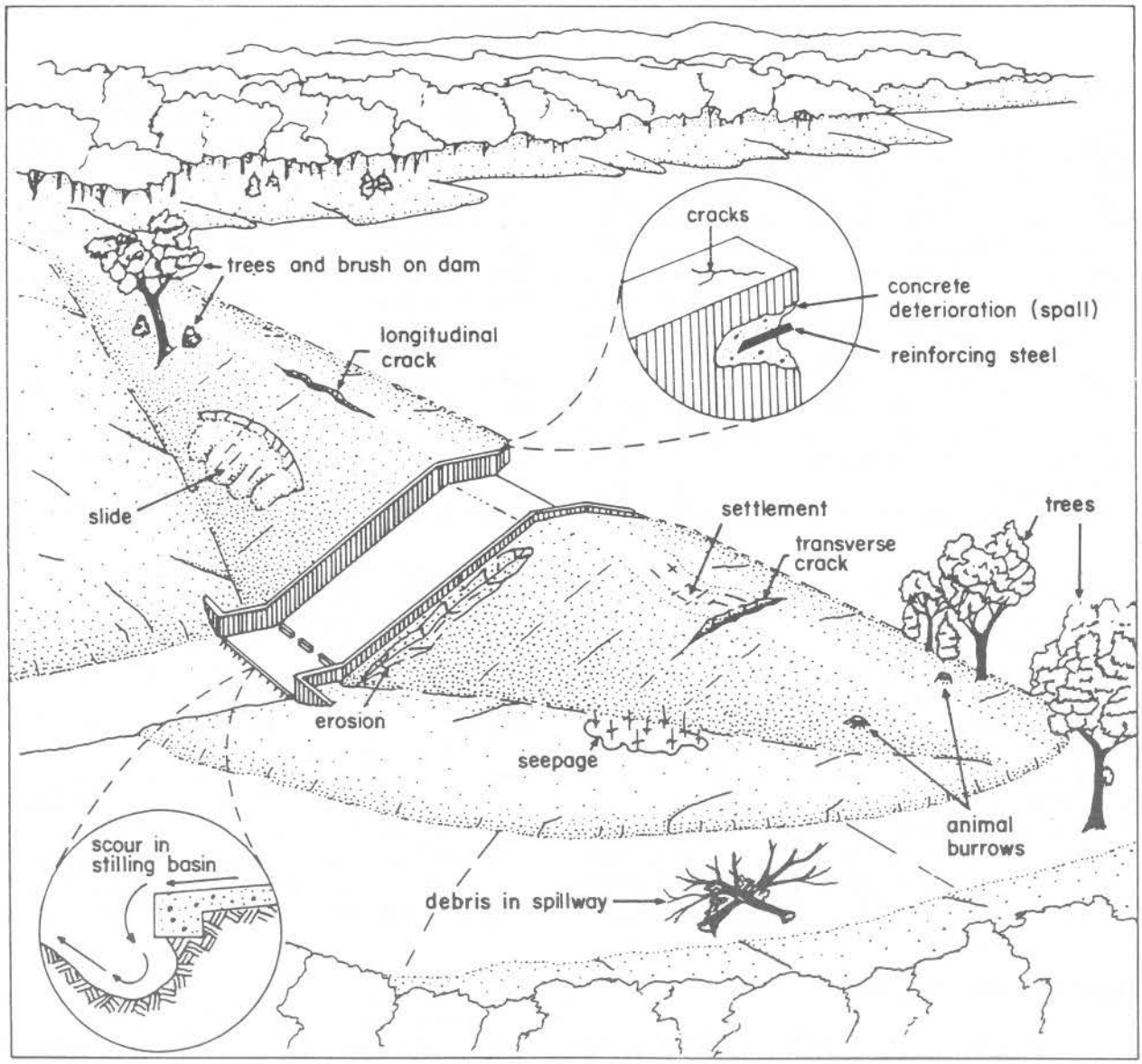

Figure 10 - Observable defects

performed by a qualified engineer with experience in the construction and inspection of dams.

Engineering inspections should be performed during modifications to an existing dam, construction of a new dam and whenever observable defects are discovered. Observable defects that require engineering inspections include slides in the embankment, uncontrolled seepage, severe erosion of spillways and discharge channels, surface cracking, concrete deterioration or cracking, separation of pipe joints, seepage around pipes, irregular settlement, and sinkholes.

An engineering inspection should include the following procedures: a review of past inspections, the history of the dam, construction plans and specifications, and an analysis of all data and information gathered including that from on-site inspections.

The review will only be as good as the data that is available to the engineer. The owner can assist the engineer in this phase of the inspection by providing the engineer with inspection records, photographs of the dam's history, information on modifications or repairs to the dam, and previous engineering reports for the dam. Some owners have kept

books or diaries of activities at the dam. This information is very useful and can include items such as visual observations, dates of inspections, visitors to the dam site, gate openings and settings, water levels, instrumentation readings, maintenance performed, and any unusual occurrences. With all of this information, the engineer can become familiar with the dam and develop a good base for a sound analysis of the structure.

The engineer's field inspection should be recorded on a checklist. The checklist is usually included in the engineer's report and should contain all available monitoring data. The inspection report should always include professional judgements, required certifications and analyses, and documentation such as field surveys and background data. The owner should insist that the engineer include in the report a description of problem areas and deficiencies, recommended remedial actions, a priority list for correcting the problems and a cost estimate for the repair items and any other inspections.

GUIDELINES ON HIRING AN ENGINEER

Finding and hiring a registered professional engineer to inspect a dam can be one of the most difficult tasks from the point of view of the owner. One of the best ways of obtaining the name of a good professional engineer is by word-of-mouth contact with other dam owners. The dam owner should contact other owners nearby and develop a list of engineers who have experience inspecting dams. The dam owner should get feedback on the engineer's qualifications, responsiveness, experience, and ability to obtain a permit. Many engineers in Missouri have experience designing dams, performing construction inspections, and inspecting existing dams. During the period 1977-1981, 607 Corps of Engineers Phase I Reports were prepared for non-federal dams in Missouri, and the vast majority of these reports were prepared by professional engineers in private practice.

Another method that the dam owner can use to identify a potential consulting engineer is by referring to specialized directories of firms prepared by the Missouri Society of Professional Engineer (MSPE) and the American Consulting Engineers Council (ACEC). The Missouri Dam and Reservoir Safety Program does not publish a list of "state certified" engineers who are qualified to design dams or prepare permit applications.

The proper way to select an engineer is by assessing the engineer's qualifications, ability to perform the work in a timely manner, and willingness to work with the owner. Selecting an engineer by comparing cost proposals or by competitive bidding can result in selecting someone who asks the lowest fee and provides the least service; therefore, the owner should be aware of the pitfalls of competitive bidding for professional engineering services. The generally accepted procedure for selecting an engineer includes the following:

1) Define the scope of work for the project;
2) Identify potential engineers;
3) Send several engineers the scope of work and request proposals;
4) Evaluate the proposals and conduct selected interviews;
5) Determine the engineer best meeting the owners needs; and
6) Negotiate the terms of the agreement and the price.

In order to evaluate potential engineers, dam owners may request that engineering firms or professional engineers submit proposals as stated in step 4. Proposals are normally requested from three or four engineers and usually contain the following information:

1) Background and experience in related work;
2) Experience in the owner's geographic area;
3) A work plan for the project;
4) Qualifications of the key personnel that will be involved.

The fee for engineering services should always be reasonable from the point of view of the owner and the engineer. This is especially true because many dams are owned by people with fixed incomes and limited resources. The fee proposal that an owner will receive from an engineer normally relates only to direct labor and administrative costs. With regard to registration permits, the condition of an existing dam is usually the most important factor in determining the cost of preparing a registration permit application. When numerous modifications are required to bring an existing dam into compliance with the law, the engineering fees will ordinarily be higher.

A written contract should be insisted upon by the engineer. In today's society, a handshake by the owner and the engineer and reliance upon good faith simply will not do. Litigation seems to be a popular course of action and it is extremely important for understandings and agreements between the dam owner and the professional engineer to be in writing. Standard agreements, such as documents, 1910-1 and 1910-2 published by the National Society of Professional Engineers, can be modified to fit any situation between a dam owner and an engineer. Copies of this agreement can be purchased from the following:

National Society of Professional Engineers
P.O. Box 96163
Washington, D. C. 20090-6163
Phone 703/684-2882

As a minimum, the contract should cover the following items:

1) A description of services to be provided by the engineer;
2) A description of any services to be provided by the owner;
3) The fee to be paid to the engineer, including payment procedure and terms;
4) Procedures for changing the scope of services;
5) Provisions for termination of the contract.

DESIGN MODIFICATIONS

Alteration of a dam or spillway without adequate engineering design and supervision can result in repairs that do not meet minimum safety standards. This can lead to additional costly repairs or complete failure of the structure. In addition, state law requires that any proposed modifications to a dam 35 feet or more in height must be approved by the Missouri Dam and Reservoir Safety Council.

One of the more common "errors" made by dam owners is raising the reservoir elevation by permanently elevating the crest of the principal spillway. This action not only results in a decrease in storage available during floods, but also reduces the capacity of the spillway by reducing the total head of water through the spillway. Raising the normal pool will usually cause the emergency spillway to flow more frequently, thus increasing maintenance costs. Furthermore, permanently raising the reservoir at a regulated dam without a construction permit is a violation of Missouri dam safety laws and associated administrative rules.

Emergency spillways usually are designed to flow once every 25 to 100 years. Because the spillway flows so infrequently, owners are tempted to find other uses for it. Temporary uses such as parking or boat launching are acceptable. Permanent alteration of the spillway shape or construction of a building or other structure in the spillway could seriously affect the spillway's ability to function properly and should not be undertaken.

VI. MAINTENANCE

SPILLWAYS

Emergency Spillways

The function of an emergency spillway is to convey flood flows past the dam in a manner that will ensure that the dam is not overtopped. Vegetated-earth, rock, and concrete spillways are commonly used as an economical means to provide emergency spillway capacity. Normal flows are carried by the principal spillway, and infrequent, large flood flows pass primarily through the emergency spillway. For dams with pipe conduit spillways, an emergency spillway is almost always required as a back-up in case the pipe becomes plugged. These spillways are often neglected because the owner rarely sees them flow. Emergency spillways usually are designed to flow only once every 25 to 100 years; however, maintenance is still very important.

Maintenance of vegetated-earth spillways should include the following:

1) *Periodic mowing to prevent trees, brush, and weeds from becoming established, and to encourage the growth of grass.* Poor vegetative cover will usually result in extensive and rapid erosion when the spillway flows, and will require more costly repairs. Trees and brush may reduce the discharge capacity of the spillway.

2) *Repair of erosion damage, particularly after high flows.* Erosion can be expected in the spillway channel during high flows and can also occur as a result of rainfall and local runoff. Local runoff is more significant in large spillways and may require special treatment, such as terraces or drainage channels. Erosion of the channel slopes deposits material in the spillway channel, especially where the slopes meet the channel bottom. In small spillways, this can significantly reduce the spillway capacity. This condition often occurs immediately after construction, before vegetation becomes established. In these cases, it may be necessary to reshape the channel to provide the necessary capacity.

3) *Seeding and fertilization as necessary to maintain a vigorous growth of vegetation.* In Missouri, fescue is an excellent grass for erosion protection in emergency spillways (see section on Vegetation).

4) *Removal or relocation of obstructions.* Emergency spillways often are used for purposes other than passage of flood flows. Among these uses are reservoir access, parking lots, boat ramps, boat storage, pasture, and cropland. Permanent structures (buildings, fences, etc.) should not be constructed in emergency spillways. If fences are absolutely necessary, they should cross the spillway far enough away from the crest (control section) so they do not interfere with flow. After flows occur, the fences should be cleared of all debris, trees, and brush.

Maintenance of rock spillways should include the periodic removal of trees, brush, and debris from flood flows and rock slides. Rock slides can be a major problem in areas where open channel spillways have been cut into weathered or highly fractured rock. Large rock that has fallen into the channel can partially block an emergency spillway and reduce its discharge capacity. Rock spillways should be inspected frequently and cleaned out whenever debris accumulates in the channel. Erosion of rock spillways is not normally a problem; however, many spillways are constructed adjacent to the dam and founded partially in rock and partially in natural soil or fill material. In these cases, a training berm is required to direct flows away from the dam. This berm and the channel side next to the

Figure 11 - Earth and rock emergency spillway

dam should be inspected for erosion whenever the spillway is used. Erosion protection consisting of riprap or concrete and designed to hold up under the velocities expected during the spillway design flood should be provided and maintained.

Maintenance of concrete spillways should include keeping the channel clear of debris, filling joints and cracks, keeping underdrains open and maintaining the structural stability of the concrete. Concrete spillways must be inspected for cracks or displacements caused by settlement, foundation failure, uncontrolled seepage, and frost action. Voids created by the settlement of compressible soils beneath spillways and uncontrolled seepage may cause the concrete to crack or displace due to lack of support. When temperatures fall below the freezing point, water located in the soil voids begins to freeze. Ice lenses can form and cause the concrete to crack and displace by a mechanism known as "frost heave." It is important to provide adequate drainage for concrete located on soil. Drains under concrete must be kept clear. Clogged or plugged drains, and inadequate filter systems can cause saturated conditions beneath the concrete. More information on concrete rehabilitation and seepage is contained in the section on Concrete Repair.

Principal Spillway Conduits

Many dams have pipes (or conduits) that serve as principal spillways. These conduits are required to carry normal stream and small flood flows safely past the embankment throughout the life of the structure. Pipes through embankments are difficult to construct properly, can be extremely dangerous to the embankment if problems develop after construction, and are usually difficult to repair because of their location and size. Maximum attention should be directed to maintaining these structures. The use of pipe whose joints are not designed to handle pressure flows, such as corrugated metal pipe, should be avoided when replacing or repairing existing pipe. The joints in a pipe can be affected by differential settlement of the embankment, bedding failure, positive and negative pressures within the pipe, and slides and seepage through the embankment. Therefore, it is imperative that pipe with pressure tight joints that can withstand minor deflections be used in a dam.

Inspection Frequent inspection is necessary to ensure the spillway conduit is functioning properly. All conduits should be inspected thoroughly once a year. Conduits which are 24 inches or more in diameter can be entered and visually inspected. The conduits should be inspected for improper alignment (sagging), separation and displacement at joints, cracks, leaks, surface wear, loss of protective coatings, corrosion, and blockage.

Figure 12 - Reinforced concrete pipe

Problems with conduits occur most often at joints, and special attention should be given them during the inspection. The joints should be checked for gaps caused by elongation or

Figure 13 - Spillway inlet structure

settlement and loss of joint-filler material. Open joints can permit erosion of embankment material or cause leakage of water into the embankment during pressure flow. The outlet should be checked for signs of water seeping along the exterior surface of the pipe. A depression in the soil surface over the pipe may be a sign that soil is being removed from around the pipe.

Repair Effective repair of the internal surface or joint of a conduit is difficult and should not be attempted without careful planning and proper professional supervision. Listed below are comments regarding pipe repairs.

1) Asphalt mastic used as joint filler becomes hard and brittle, is easily eroded, and will generally provide a satisfactory seal for only about five years. Mastic should not be used if the pipe is expected to flow under pressure. For these reasons asphalt mastic is not recommended for other than temporary repairs.

2) The instructions on the label should be followed when using thermosetting plastics (epoxy). Most of these products must be applied to a very clean and dry surface to establish an effective bond.

3) Material used as joint filler should be impervious to water and should be flexible throughout the range of expected air and water temperatures.

4) The internal surfaces of the conduit should be made as smooth as possible when repairs are made so that high-velocity flow will not damage the repair material.

5) Hairline cracks in concrete are not generally considered a dangerous problem and repair is not needed unless the cracks open up or transmit water.

Corrosion A common problem with pipe spillways and other conduits made of metal is corrosion. Exposure to moisture, acid conditions, or salt will accelerate the corrosion process. Acid runoff from strip-mine areas will cause rapid corrosion of metal pipes. In these areas, pipes made of non-corrosive materials such as concrete or plastic should be used.

Metal pipes are available which have been coated to resist accelerated corrosion. Coatings can be of epoxy, aluminum, or zinc

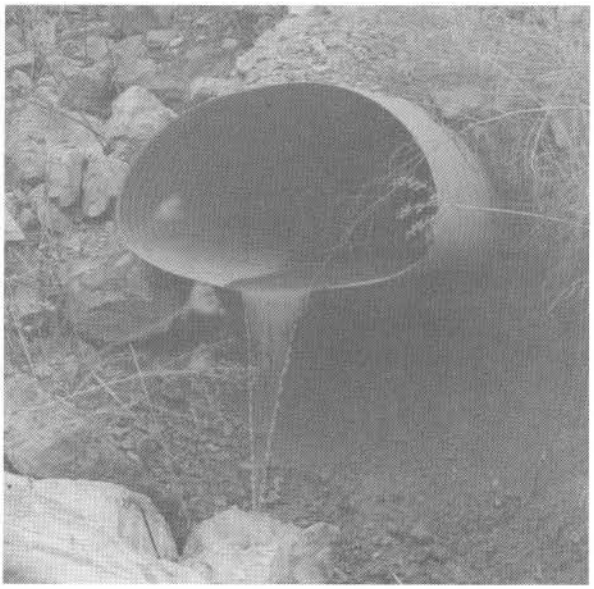

Figure 14 - Corrugated metal pipe through a dam

(galvanized). Coatings applied to pipes in service are generally not very effective because of the difficulty in establishing a bond. Bituminous coatings cannot be expected to last more than one or two years on flow ways.

Corrosion can be controlled or arrested by installing cathodic protection. A metallic anode such as magnesium is buried in the soil and is connected to the metal pipe by wire. Natural voltage causes current to flow from the magnesium (anode) to the pipe (cathode) and will cause the magnesium to corrode and not the pipe.

Corrosion shortens the life of metal pipes through dams. The corrosion rate is dependant upon the soil PH, water content, metal thickness, and overburden load. All metal pipes need to be closely monitored with respect to operation of the pipe.

Corrosion of metal parts of operating mechanisms can be effectively treated and prevented by keeping these parts oiled and/or painted.

Undermining of the Spillway Outlet Erosion at the spillway outlet, whether it be a pipe or overflow spillway, is one of the most common spillway problems encountered. Severe undermining of the outlet can displace sections of pipe, cause slides in the downstream slope of the dam as erosion continues, and

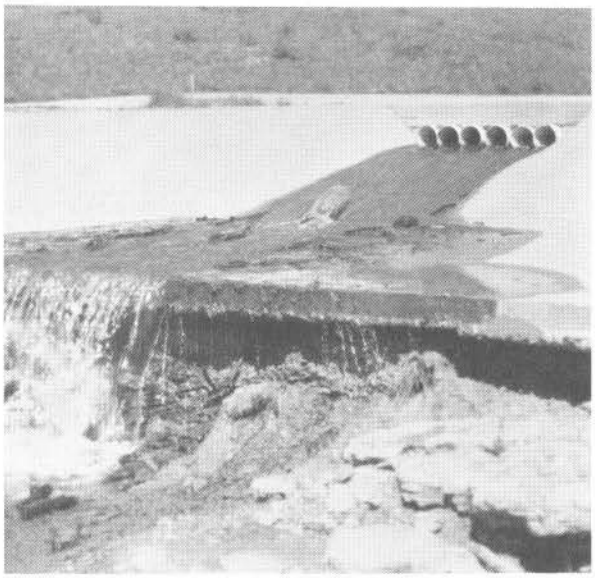

Figure 15 - Erosion of spillway outlet

eventually lead to complete failure of a dam. Water must be conveyed safely from the lake to a point downstream of the dam without endangering the spillway or embankment.

Often the spillway outlet is adequately protected for normal flow conditions, but not for extreme flows. It is easy to underestimate the energy and force of flowing water or overestimate the resistance of the outlet material (earth, rock, concrete, etc). The required level of protection is hard to establish by visual inspection but can usually be determined by hydraulic calculations performed by a professional engineer.

Structures that provide complete erosion control at a spillway outlet are usually expensive to construct, but often necessary. Less expensive types of protection can be effective, but require more extensive periodic maintenance. As areas of erosion and deterioration develop, repairs must be promptly initiated.

The following four factors, often interrelated, contribute to erosion at the spillway outlet.

1) Flows emerging from the outlet are normally at an elevation above the stream channel. If the outlet flows emerge at the correct elevation, tailwater in the stream channel can absorb a substantial amount of the high velocity flow.

2) Flows emerging from the spillway are generally free of sediment and therefore have substantial sediment- carrying capacity. In obtaining the appropriate sediment load, the moving water will scour soil material from the channel and leave eroded areas. Such erosion is difficult to estimate and requires that the outlet be protected for a safe distance downstream from the dam.

3) Flows leaving the outlet at high velocity can create negative pressures that can cause material to be loosened and removed from the floor and walls of the outlet channel. This action is known as "cavitation" and can affect concrete or metal surfaces. Venting can sometimes be used to relieve negative pressures; however, the size and location of a vent should be determined by a professional engineer.

4) Water leaking through pipe joints or flowing along a pipe from the reservoir may weaken the soil structure around the pipe. Inadequate compaction adjacent to the structure during construction and the absence of anti-seep collars or sand diaphragms will compound the problem.

Eroded and undermined areas at spillway outlets can sometimes be repaired by filling these areas with large stone. Stone that is large enough to be effective needs to weigh in excess of 500 pounds (18 to 24 inches in diameter). Often stones this size are not available or are expensive to buy and haul. Owners should be aware that placing large stones in the undermined areas adjacent to spillway outlets may not solve a problem. Often these eroded areas are a result of a more serious problem with the dam. Gabions have been used successfully in areas where the velocity is low but should not be used where high velocity and turbulence are expected. Gabions require careful foundation preparation and experienced personnel for installation. Properly designed plunge pools are acceptable but can require frequent maintenance.

In many cases, professional help should be sought for complete redesign and construction of the outlet.

Trashracks

Many dams have pipe and riser spillways. Pipe spillway inlets that become plugged with debris or trash reduce spillway capacity. As a result, the potential for overtopping the dam is greatly increased, particularly if there is only one spillway. If the dam has an emergency spillway channel, a plugged principal spillway will cause more frequent and greater flow in the emergency spillway. Because emergency spillways are generally designed for infrequent flows of short duration, serious damage will likely result. For these reasons, trashracks or collectors must be installed at the inlets to pipe spillways and lake drains.

A well-designed trashrack will stop large debris that could plug the pipe but allow unrestricted passage of water and smaller debris. Some of the most effective trashracks allow flow to pass beneath the trashrack into the riser inlet as the pool level rises. Trashracks usually become plugged because the openings are too small or the head loss at the rack causes material and sediment to settle and accumulate. Small openings will stop small debris such as twigs and leaves, which in turn cause a progression of larger items to build up, eventually blocking the inlet. Trashrack openings should be at least 6 inches across regardless of the pipe size. The larger the principal spillway conduit, the larger the trashrack opening should be. The largest possible openings should be used, up to a maximum of about 12 inches.

Figure 16 - Trashrack on spillway inlet

The trashrack should be properly attached to the riser inlet and strong enough to withstand the hammering forces of debris being carried by high-velocity flow, a heavy load of debris, and ice. If the riser is readily accessible, vandals will throw riprap and debris into it. To prevent such vandalism, the size of the trashrack openings should not be decreased, but rock that is larger than the openings, too large to handle, or covered with concrete slurry should be used.

Maintenance should include periodic inspections for rusted and broken sections and repairs made as needed. The trashrack should be checked frequently during and after storms to ensure it is functioning properly and to remove accumulated debris.

Concrete Repair

Concrete is an inexpensive, durable, strong, basic building material often used in dams for core walls, spillways, stilling basins, control towers, and slope protection. However, poor workmanship, construction procedures, and materials may cause imperfections that later require repair. Long term deterioration or damage caused by flowing water, ice, or other natural forces must be corrected.

Inspection Concrete surfaces should be examined for spalling and deterioration due to weathering, unusual or extreme stresses, alkali or other chemical action, erosion, cavitation, vandalism, and other destructive forces.

Structural problems are indicated by cracking, exposed reinforcing bars, large areas of broken-out concrete, misalignment at joints, undermining, and settlement. Rust stains may indicate internal rusting and deterioration of reinforcement steel. Spillway floor slabs and upstream-slope protection slabs should be checked for undermining (erosion of base materials). Concrete wall and tower structures should be examined for settlement and their alignment checked. Concrete surfaces adjacent to contraction joints and subject to flowing water are of special concern. The adjacent surfaces must be flush or the downstream edge slightly lower to prevent erosion of the concrete and to prevent water from being directed into the joint during high-velocity flow. All joints should be kept free of vegetation. All weep holes should be checked for blockage, and concrete-stain

Figure 17 - Concrete deterioration and exposed reinforcing steel

outlines on concrete surfaces studied for indications of flow characteristics.

General Concrete Repair Floor or wall movement, extensive cracking, improper alignments, settlement, joint displacement, and extensive undermining are signs of major structural problems. Drainage systems may be needed to relieve excessive water pressures under floors and behind walls. Because of their complex nature, major structural repairs require professional advice and are not addressed here.

Before attempting repair of a concrete surface, all unsound concrete should be removed by sawing or chipping and the patch area thoroughly cleaned. A sawed edge is superior in every way to a chipped edge, and sawing is generally less costly than mechanical chipping.

The Bureau of Reclamation (1981) recommends the following six methods of concrete repair. These techniques require expert and experienced assistance for the best results. The particular method of repair will depend on the size of the job and the type of repair required.

1) The Dry-Pack Method - The dry-pack method can be used on small holes in new concrete which have a depth equal to or greater than the surface diameter. Prepare a dry-pack mix consisting of 1 part cement to 2½ parts sand. Add enough water to produce mortar that will stick together. Pack the mortar into the hole in thin layers.

2) Concrete Replacement - Concrete replacement is required when ½- to 1-square-foot areas or larger extend entirely through the concrete section or where the depth of damage exceeds 6 inches. Normal concrete placement methods should be used. The repair will be more effective if tied in with the existing reinforcing steel (rebar).

3) Replacement of Unformed Concrete - The replacement of damaged or deteriorated areas in horizontal slabs involves no special procedures other than those used in good construction practices for placement of new slabs. Repair work can be bonded to old concrete by use of a bond coat made of equal amounts of sand and cement. It should have the consistency of whipped cream and should be applied immediately before concrete placement so that it will not set or dry out. Latex emulsions with portland cement and epoxy resins are also used as bonding coats.

4) Shotcrete (Gunite) - A popular concrete replacement technique for repairing large areas of severely deteriorated concrete and spalled vertical and overhead faces is the use of pneumatically placed concrete or shotcrete. Shotcrete consists of a mixture of moistened cement and fine aggregate (sand) that is sprayed onto the repair area

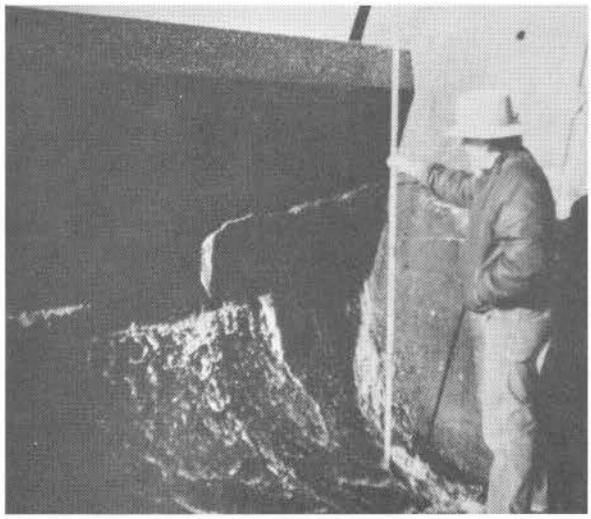

Figure 18 - Cracks in concrete spillway

under pressure. Steel and synthetic fibers can be included in the shotcrete for reinforcement. Professional assistance and sophisticated equipment are needed to apply shotcrete.

5) Prepacked Aggregate with Intruded Mortar - A special commercial technique has been used for massive repairs, particularly for underwater repair of piers and abutments. The process consists of a) removing the deteriorated concrete; b) forming the sections to be repaired; c) prepacking the repair area with coarse aggregate; and d) pressure-grouting the voids between the aggregate particles with a cement or sand-cement mortar.

6) Synthetic Patches - One of the most recent developments in concrete repair has been the use of synthetic materials for bonding and patching. Epoxy-resin compounds are used extensively because of their high-bonding properties and great strength. In applying epoxy-resin patching mortars, a bonding coat of the epoxy resin is thoroughly brushed onto the base of the old concrete. The mortar is then immediately applied and struck off to the elevation of the surrounding material.

When to Use Each Method Epoxy-bonded mortar can be used when the depth of repair is less than 1½ inches. Epoxies can be used to bond new concrete or mortar to old concrete whenever the depth of repair is between 1½ and 6 inches. Concrete replacement techniques (methods 2, 3, 4, or 5) should be used when the depth of repair exceeds 6 inches or the repair area is large.

All concrete repairs must be adequately moist-cured to be effective. The bond strength of new concrete to old concrete develops much more slowly, and the tendency to shrink and loosen is reduced by a long moist-curing period.

Repair of Cracks Repair of cracks in structures that carry water requires great care and preparation. The following steps are recommended by the Bureau of Reclamation (1981), See Figure 18.

1) Cut a groove, ½ inch wide and 2 to 2½ inches deep, along the crack. A power-driven saw-tooth bit works satisfactorily;

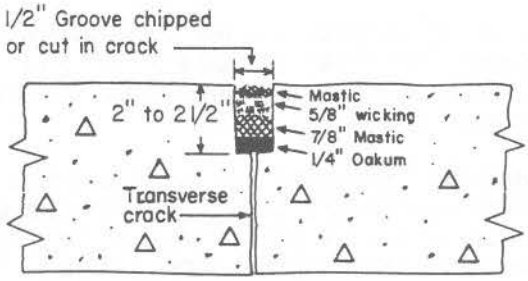

Figure 19 - Concrete crack repair

2) Rub a thin layer of internal-set-type mastic onto the interior surfaces of the groove;

3) Tamp oakum tightly into the bottom ¼ inch of the slot;

4) Fill in 7/8 inch of mastic on top of the oakum;

5) Place a 5/8 inch section of tightly twisted rope wicking into the groove and caulk tightly with pneumatic tools; and

6) Fill the groove with mastic and smooth the surface.

Seepage

All dams, regardless of type, have seepage in one form or another. Seepage may be through the foundation, through the embankment, or along the foundation-embankment interface. The seepage volumes may be substantial or barely noticeable. The water may be transporting suspended or dissolved

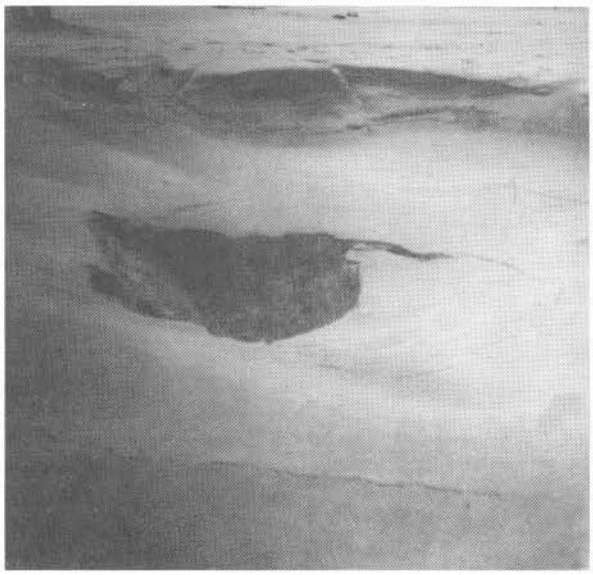

Figure 20 - Sinkhole caused by uncontrolled seepage

solids. In some cases, the seepage may be entirely harmless; in others, it may be extremely serious and immediate treatment becomes imperative.

Detection Seepage can emerge anywhere on the downstream face of the dam, beyond the toe, or on the downstream abutments at elevations below normal pool. Seepage may vary in appearance from a "soft", wet area to a flowing channel of water. It may show up first as only an area where the vegetation is more lush and darker green. Cattails, reeds, mosses, and other marsh vegetation often become established in a seepage area. Downstream groin areas (the areas where the downstream face contacts the abutments) should always be inspected closely for signs of seepage. Seepage can also occur along the contact between the embankment and a conduit spillway, drain, or other appurtenance. Slides in the embankment or an abutment may be the result of seepage causing soil saturation or loss of soil strength.

At most dams, some water will seep from the reservoir through the foundation. Where it is not intercepted by a subsurface drain, the

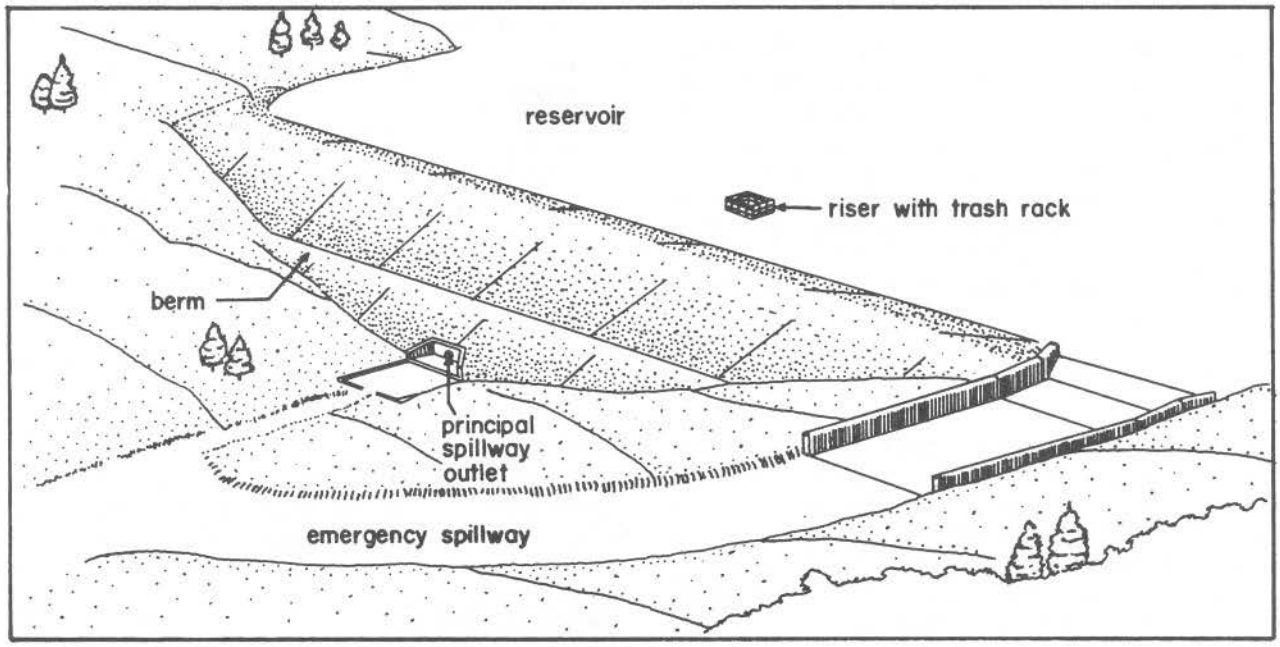

Figure 21 - Embankment dam

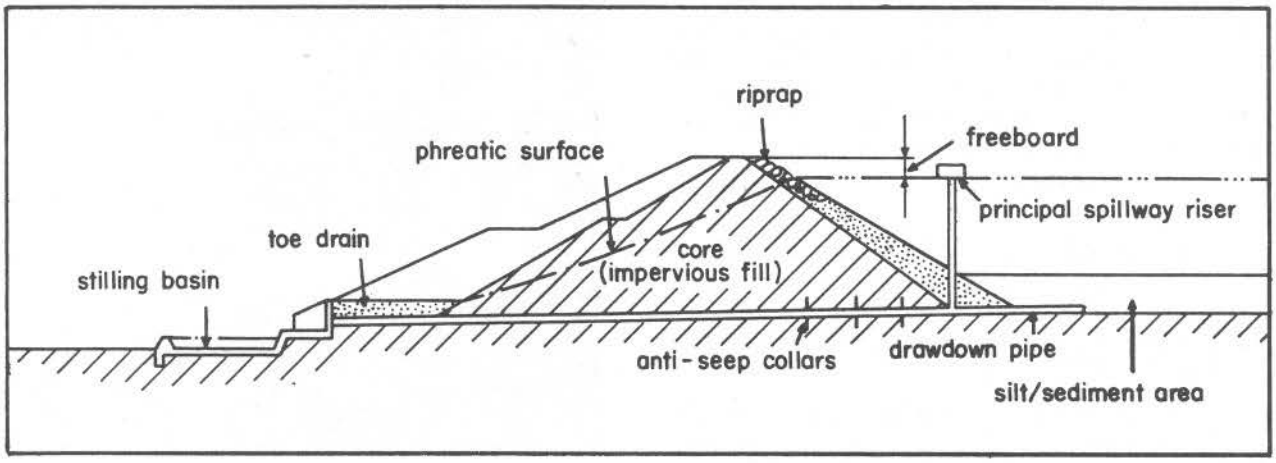

Figure 22 - Section through dam

seepage will emerge downstream from or at the toe of the embankment. If the seepage forces are large enough, soil will be eroded from the foundation and deposited in the shape of a cone around the outlet. If these "boils" appear, professional advice should be sought immediately. Seepage flow which is muddy and carrying soil particles may be evidence of "piping," and complete failure could occur within hours. Piping can occur along a spillway and other conduits through the embankment, and these areas should be closely inspected. Sinkholes that develop on the embankment above buried conduits are signs that piping has begun and a professional engineer should immediately be retained to investigate the situation. If the extent of piping is large enough, rapid and complete failure of the dam could be imminent. Emergency procedures, including downstream evacuation, must be implemented if this condition is noted.

A continuous or sudden drop in the normal lake level may be an indication that seepage is occurring. In this case, one or more locations of flowing water are usually noted downstream from the dam. This condition in itself may not be a serious problem, but will require frequent, close monitoring and professional assistance.

Control The need for seepage control will depend on the quantity, content, and location of the seepage. Other factors to be considered when evaluating seepage problems include the seepage path and pattern, configuration of the dam, and the engineering properties of the embankment materials. Controlling the quantity of seepage that occurs after construction is difficult, quite expensive, and not usually attempted unless drawdown of the pool level has occurred or the seepage is endangering the embankment or appurtenant structures. Typical methods used to control the quantity of seepage are grouting, installation of an upstream blanket, or slurry walls. Relief wells can be installed to relieve the water pressure in the foundation. Grouting is most applicable to leakage zones in bedrock, abutments, and foundations. Extreme care should be exercised when grouting in fill material. All these methods must be designed and constructed under the supervision of a professional engineer experienced with dams.

Controlling the content of the seepage or preventing seepage flow from removing soil particles is extremely important. Modern design practice incorporates this control into the embankment through the use of cutoffs, internal filters, and adequate drainage provisions. Control at points of seepage exit can be accomplished after construction by using weighted filters, drain pipes, trench drains, and other methods of drainage. The filter and drainage system should be designed to prevent migration of soil particles and still provide for passage of the seepage flow. Geotextiles or synthetic fabrics have worked quite well as filters in many applications; and should be considered by the engineer and the owner as a means of controlling seepage. The bottom layer of the weighted filter should include 6 to 12 inches of sand placed over the seepage area. A properly designed geotextile should be placed beneath the sand or the gradation of the sand should be based on the particle sizes of the foundation or fill material. The sand layer should be covered with a gravel layer of similar thickness. Larger rock should be placed next, to complete the berm. This method will permit the seepage to drain freely, but prevent piping (removal) of soil particles. The weight of the berm will hold the filter in place and may also provide additional stability to the embankment and foundation.

The location of the seepage or wet area on the embankment or abutment is often a primary concern. Excessive seepage pressure or soil saturation can threaten the stability of the downstream slope of the dam or the abutment slopes. An abutment slide might block or damage the spillway outlet or other appurtenances. In these cases, not only must the seepage be controlled but the area must be dried out. This is sometimes accomplished by installing finger drains (lateral trench drains for specific locations). Seepage control systems must always be free-draining to be effective.

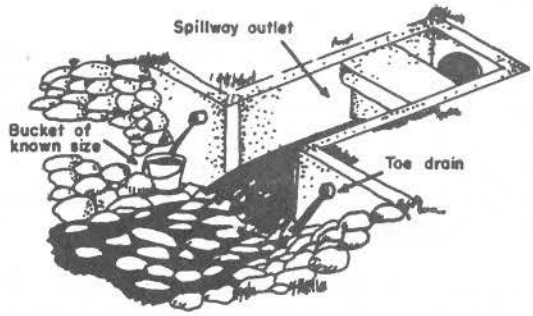

Figure 23 - Monitoring quantity of seepage through toe drains

Monitoring Regular monitoring is essential to detect seepage and prevent failure. Without knowledge of the dam's history, the owner or the inspector has no idea whether the seepage condition is in a steady or changing state. It is important to keep written records of points of seepage exit, quantity and content of flow, size of wet area, and type of vegetation for later comparison. Photographs provide invaluable records of seepage. The inspector should always look for increases in flow and evidence of flow carrying soil particles. The control methods described previously are often designed to facilitate observation of flows. It is highly recommended that a v-notch weir be included in the design of a filter and drain system to measure the flow rates.

Regular surveillance and maintenance of internal embankment and foundation drainage outlets is also required. Normal maintenance consists of removing any soil or other material that obstructs flow. Internal repair is complicated and often impractical and should not be attempted without professional advice. The rate and content of flow emerging from these outlets should be monitored regularly.

EMBANKMENT CRACKS AND SLIDES

The embankment and any appurtenant dikes must safely contain the reservoir. Cracks, slides, sloughing, and settlement are signs of embankment distress and indicate that maintenance or remedial work is required. The cause of the distress should be determined by an experienced professional engineer before undertaking repairs on dams 35 feet or more in height. This step is important because a so-called "home remedy" may cause greater and more serious damage to the embankment and may eventually result in unwise expenditures for useless repairs.

Cracks

The entire embankment should be closely inspected for cracks. Short, isolated cracks are not usually significant, but larger (wider than 1 or 2 inches), well-defined cracks may indicate a more serious problem. There are three types of cracks: transverse, longitudinal, and diagonal (See Figure 10).

Transverse cracks appear across the embankment and indicate differential settlement within the embankment. Such cracks provide avenues for seepage water and piping could develop quickly.

Figure 24 - Cracks in crest of dam

Longitudinal cracks run parallel to the embankment and may signal the early stages of a slide on either face of the embankment. In recently built structures, these cracks may indicate inadequate compaction of the embankment during construction.

Diagonal cracks are intermediate vertical cracks that form in the embankment as a result of slides or differential settlement.

Dams built where the surface soils consist of loess have sometimes developed relatively wide cracks. Loess is interpreted as ancient, windblown materials, which consist mostly of silt with grains sizes ranging from clay to fine sand. Because Missouri has several regions of prominent loess soils, dams built with this material should be monitored closely for cracks after construction.

Small cracks, as they appear, should be documented, examined by an engineer, and then sealed. The seal will prevent surface water from entering the cracks, causing saturation of embankment material, and possibly triggering a slide or other serious problem. Sealing can be accomplished by compacting clay in the cracks. Unless the cracks are large (wider than an inch), this can usually be done in a few minutes using a shovel and a compacting tool. After the cracks have beer

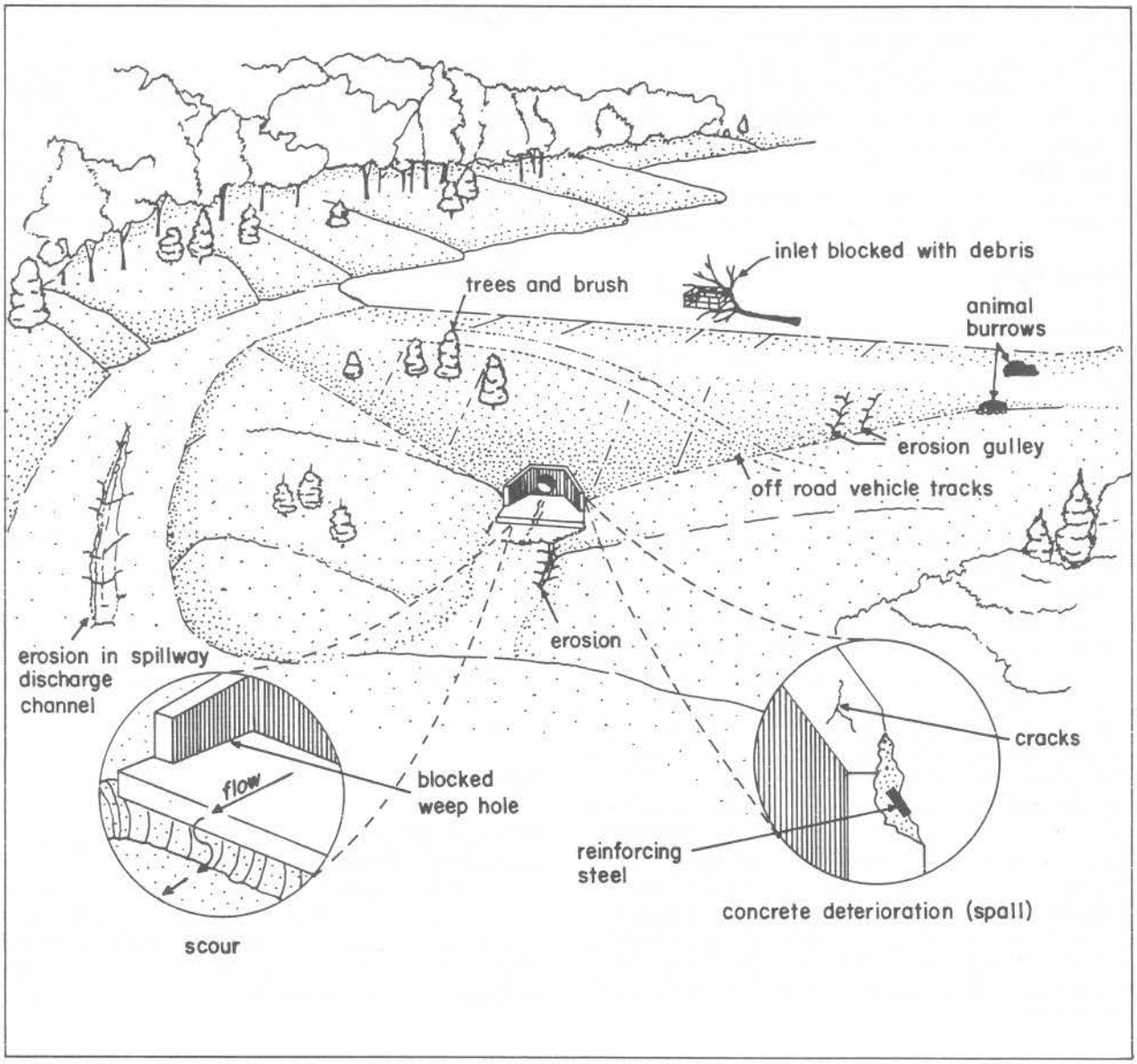

Figure 25 - Common maintenance deficiencies at a dam

sealed, the areas should be monitored frequently to determine if movement is still occurring. Slides or crack locations can be documented by staking and photographs. Continued movement is an indication of a more serious problem such as a slide.

Slides

Slides and sloughs are serious threats to the safety of a dam. A massive slide can initiate catastrophic failure of a dam. Slides can be detected easily unless obscured by tall vegetation. Arc-shaped cracks are indications that a slide or slough is beginning. These cracks soon develop into a large scarp in the slope at the top of the slide.

If a slide develops, the scarp should be sealed to prevent rainfall and surface runoff from lubricating the interior slide surface, saturating the embankment, and causing future sliding. Sealing the scarp is only a temporary measure. The need for immediate professional assistance to determine the cause of cracks and slides and to recommend remedial action cannot be overemphasized.

Slide debris in spillway and outlet areas should be removed immediately, because the debris reduces hydraulic capacities. Shallow surface slides can be repaired by removing the slide material and rebuilding the slope to original grade with well compacted impervious clay material. The cause for any slide should be fully determined before implementing permanent repairs to the slope.

Settlement

Settlement occurs both during construction and after the embankment has been completed and placed in service. To a certain degree, this is normal and should be expected. Settlement is usually most pronounced at locations of maximum foundation depth or embankment height. Excessive settlement will reduce the freeboard (the difference in elevation between the water surface and the top of the dam) and may increase the probability of overtopping. Any areas of excessive settlement should be restored to original elevations and conditions to reduce the risk of overtopping. A relatively large amount of settlement (more than one foot) within a small area could indicate serious problems in the foundation or perhaps in the lower part of the embankment. Settlement accompanied by cracking often precedes failure. When either condition is observed, professional advice should be sought. Settlement can be monitored by measuring the differences in elevation between the problem area and permanent reference monuments located away from the dam. Land surveying instruments are required to make these measurements.

Repair

Repair of cracks, slides, and settlement in dams 35 feet or more in height requires the removal of all unsuitable material and the addition of good material to the embankment. Filters and drains may also be necessary to correct these problems. Soil added to restore an embankment should be properly "keyed" into the base material. This can best be accomplished by removing the vegetal cover and all unsuitable material until a good, firm base in undisturbed soil is uncovered. Unsuitable materials include wet, soft, porous, organic, and improperly compacted soils. The surface should then be roughened with a disc or similar device to obtain a good bond between "old" and "new" materials. The new soil should be successively placed in thin layers (6 to 8 inches thick) and each layer compacted before adding more material. Compaction of each layer to at least 95 percent maximum dry density at 1 percentage point below to 3 percentage points above optimum moisture content based on the Standard Proctor Density Test (ASTM D698) is recommended for cohesive soils used in small dams.

EROSION

Erosion of slopes, abutments, and spillway discharge channels is one of the most common maintenance problems with embankment structures. Erosion in and around dams can play a dual role in that it can be both the cause and effect of defects and, if left untreated, can lead to failure of a dam.

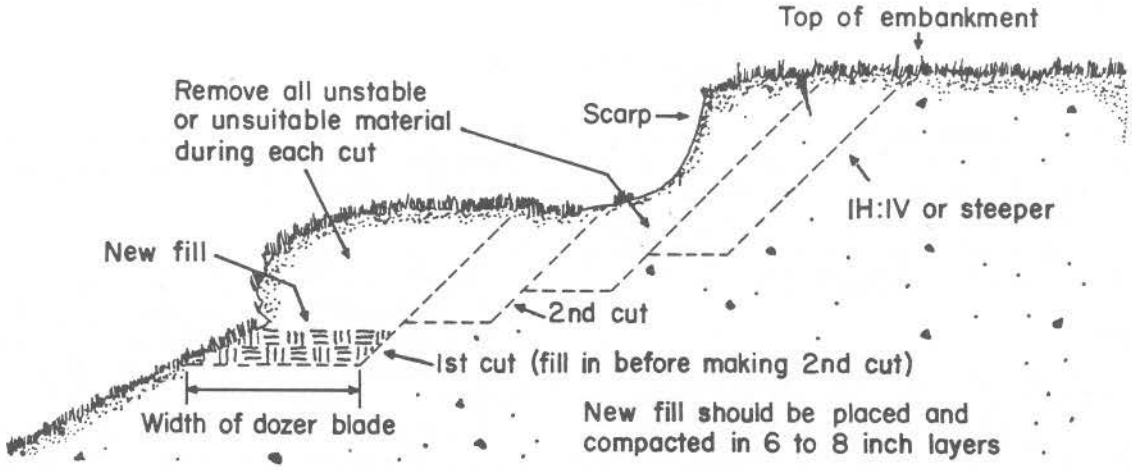

Figure 26 - Repair of slides

Erosion is a natural process, and its continuous forces will eventually wear down almost any surface or structure. Periodic and timely maintenance is essential in preventing continuous deterioration and possible failure.

Vegetated Surfaces

A sturdy sod, free of weeds and brush, is one of the most effective means of erosion protection. Embankment slopes are normally designed and constructed so that the surface drainage will be spread out in thin layers as "sheet flow" on the grassy cover. When the sod is in poor condition or flows are concentrated at one or more locations, the resulting erosion will leave rills and gullies in the embankment slope. The owner or inspector should look for these areas and be aware of the problems that may develop.

Prompt repair of vegetated areas that develop erosion is required to prevent more serious damage to the embankment. Rills and gullies should be filled with suitable soil (the upper 4 inches should be topsoil, if available), compacted, and then seeded. Methods described in the section on Vegetation should be used to properly establish the grass surface. Erosion in large gullies can be slowed by stacking bales of hay or straw across the gully until permanent repairs can be made.

Not only should the eroded areas be repaired, but the cause of the erosion should be addressed to prevent a continuing maintenance problem. Erosion might be aggravated by improper drainage, settlement, pedestrian traffic, animal burrows, or other forces. The cause of the erosion will have a direct bearing on the type of repair needed.

Paths from pedestrian traffic are problems common to many embankments. If a path has become established, vegetation in this area will not provide adequate protection and more durable cover will be required, unless the traffic is eliminated. Small stones, asphalt, or concrete have been used effectively to cover footpaths. Embedding railroad ties or other treated wood beams into the upstream slope of the embankment to form steps is one of the most successful and inexpensive methods used to provide a protected pathway. Barriers should be constructed along paths used by motorcycles and off-road-vehicles "ORV's" to discourage their use on a dam.

Figure 27 - Erosion on downstream slope of dam

Another area where erosion commonly occurs is the contact between the embankment and the concrete walls of the spillway or other structures. Poor compaction adjacent to the wall during construction and subsequent settlement could leave an area lower than the grade of the embankment. Runoff often concentrates along these structures, resulting in erosion. People frequently walk along these walls, wearing down the vegetal cover. Possible solutions include grading the area to slope away from the wall and adding more resistant surface protection.

Groin Areas

Adequate erosion protection is required along the contact between the downstream face of the embankment and the abutments. Runoff from rainfall concentrates in these gutter areas and can reach erosive velocities because of the steep slopes. Berms on the downstream face that collect surface water and empty into these gutters add to the runoff volume. Sod gutters may not adequately prevent erosion in these areas. Paved concrete gutters do not hold up well, will not slow the velocity of the water, can become undermined, and therefore are not recommended. Groundhogs often construct burrows underneath concrete gutters, possibly because burrowing is easier due to existing undermining.

A well graded mixture of rock with stones 9 to 12 inches in diameter or larger placed on a sand filter generally provides the best protection on small dams. Slush-grouted riprap (riprap filled with a thin concrete slurry) has also been successful in preventing erosion and can be used if large stone is not available or for groins of larger dams. A properly designed filter should be constructed beneath the slush grouted riprap.

Upstream Slope

A serious erosion problem which can develop on the upstream slope is "beaching." Waves caused by high winds or high-speed power boats can erode the exposed face of the embankment. Waves repeatedly strike the surface just above the pool elevation, rush up the slope, then tumble downward into the pool. This action erodes material from the face of the embankment and displaces it farther down the slope, creating a "beach". Erosion of unprotected soil can be rapid and during a severe storm could lead to complete failure of a dam.

The upstream face of a dam is commonly protected against wave erosion and the resultant beaching by placement of a layer of rock riprap over a layer of filter material. In some cases other materials such as steel, bituminous or concrete facing, bricks or concrete blocks are used. Generally, rock riprap provides the most economical protection.

Beaching can also occur in existing riprap if the embankment surface is not properly protected by a filter. Water running down the slope under the riprap can erode the embankment. Sections of riprap slumped downward are often signs of beaching. Concrete facing used to protect slopes often fails because the wave action washes soil particles from beneath the slabs through joints and cracks. Detection, in this case, is difficult because the voids are hidden and failure may be sudden and extensive. Effective slope protection **must** prevent soil particles from being removed from the embankment.

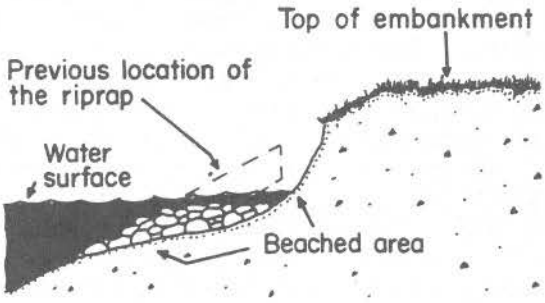

Figure 28 - Upstream slope erosion

When erosion occurs and beaching develops on the upstream slope of a dam, repairs should be made as soon as possible. The pool level should be lowered and the surface of the dam prepared for replacing the slope protection. A small berm or "bench" should be made across the face of the dam to help hold the protective layer in place. The bench should be placed at the base of the new layer of protection. The depth of the bench will depend on the thickness of the protection layer. See Figure 29.

The layer should extend a minimum of 3 feet below the lowest anticipated pool level. Otherwise, wave action during periods when the lake level is drawn down can undermine and destroy the protective layer.

If rock riprap is used, it should consist of a heterogeneous mixture of irregular shapes placed over a sand and gravel filter. The maximum rock size and weight must be large enough to break up the energy of the maximum anticipated wave action and hold the small stones in place. Generally, the largest stones should be at least 12-24 inches in diameter. The smaller rocks help to fill the spaces between the larger pieces forming a resistant mass. The filter prevents soil particles on the embankment surface from being washed out through the spaces (or voids) between the rocks in the riprap. If the filter material can be washed out through these voids and beaching develops, two filter layers will be required. The lower layer should be composed of sand or filter fabric to protect the soil surface. The upper layer should be composed of coarser materials that prevent washout through the voids in the riprap.

A dam owner should expect some deterioration (weathering) of riprap. Freezing and thawing, wetting and drying, abrasive wave action, and other natural processes will eventually break down the riprap. Its useful life varies with the characteristics of the stone used. Stone for riprap should be rock that is dense and well cemented. Due to the high initial cost of rock riprap, its durability should

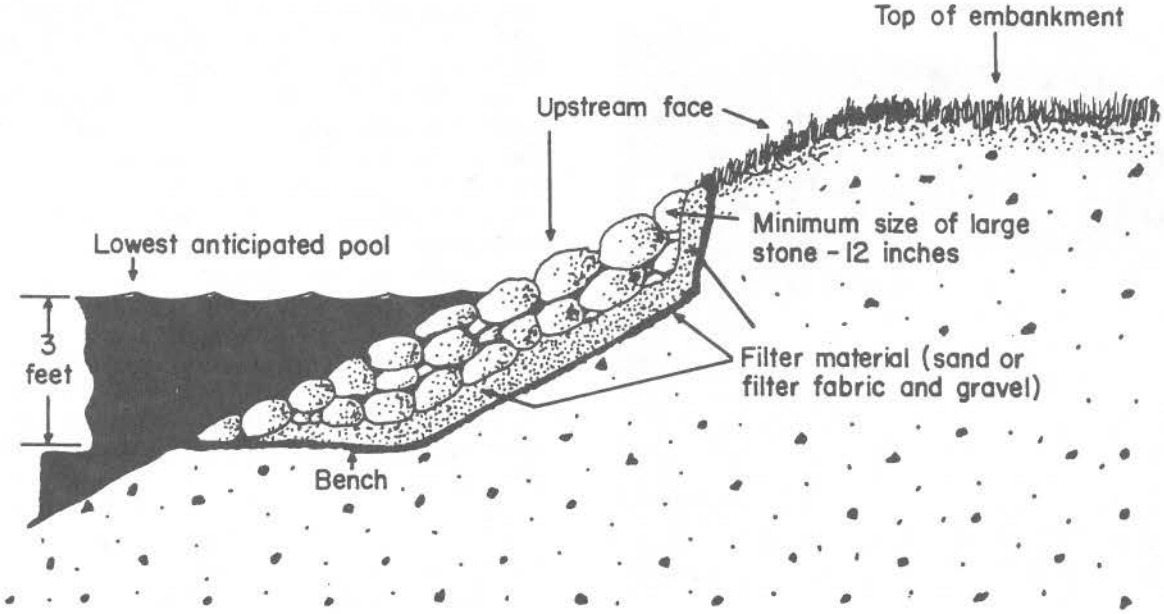

Figure 29 - Riprap for wave protection

be determined by appropriate testing procedures prior to installation.

VEGETATION

The establishment and control of proper vegetation is an important part of dam maintenance. Properly maintained vegetation can help prevent erosion of the embankment and earth channel surfaces, and aid in the control of groundhogs and muskrats. The uncontrolled growth of vegetation can damage embankments and concrete structures and make close inspection difficult.

Grass Vegetation

Grass vegetation is an effective and inexpensive way to prevent erosion of embankment surfaces. If properly maintained, it also enhances the appearance of the dam and provides a surface that can be easily inspected. Roots and stems tend to trap fine sand and soil particles, forming an erosion-resistant layer once the plants are well established. Grass vegetation is least effective in areas of concentrated runoff, such as the contact of the embankment and abutments, or in areas subjected to wave action.

Types of grass vegetation that have been used on dams in Missouri are fescue, rye grass, bluegrass, Bermuda grass, brome and reed canary grass. Sericea Lespedeza and crown vetch are not recommended in the spillway or on the dam.

Establishing vegetation on a dam depends on where the dam is located in Missouri, the type of soil, the steepness of slope, and the orientation of the embankment. The vegetation proposed for the groin area and emergency spillway areas where there is flowing water might be different than the vegetation proposed for the steep slopes of the embankment. Owners may wish to contact the local field office of the Soil Conservation Service or the local county extension office for recommendations on the establishment of this vegetation.

Before seeding unvegetated areas, fertilizer and lime should be applied. Exact quantities necessary will vary with soil type and condition, and can be determined by having the soil tested. The fertilizer and lime should be raked, disked, or harrowed into the soil to a depth of not less than 4 inches. Periodic fertilization may be necessary to maintain vigorous vegetation.

The seed should be thoroughly mixed and evenly sown. The rate of seeding depends on the type of seed, percent purity, percent germination, and whether or not it is being incorporated into a seedbed, or applied as a dominant seeding on top of the ground. The seed should be covered with soil to a depth

Figure 30 - Grass cover on slope

of approximately 1/4 inch or rolled sufficiently. Immediately following planting, the area should be mulched with hay or straw at a rate of 2 to 3 tons per acre. Mulching materials should be kept in place with a mulch anchoring device or with asphalt emulsion.

Crown vetch (Coronilla varia) a perennial plant with small bi-colored (pink and white) flowers, has been used on some dams in Missouri but is not recommended. Crown vetch obscures the embankment surface, preventing early detection of cracks, erosion, and other damage. Large weeds, brush and trees can become established and periodic hand labor is then required to remove unwanted tall vegetation. Crown vetch is not effective in preventing erosion in some areas and is also expensive to establish.

Sericea Lespedeza (Lespedeza cuneata), an upright perennial summer legume, is used by the State Highway Department on road cuts, but it is not recommended for use on dams or spillways. Sericea Lespedeza grows to a height of 3 to 5 feet. It grows in clumps, attracts burrowing animals, and obscures the surface of the dam. Sericea Lespedeza is not effective in preventing surface erosion.

Trees and Brush

Trees and brush should not be permitted on embankment surfaces or in vegetated earth spillways. Extensive root systems can provide seepage paths for water. Trees that blow down or fall over can leave large holes in the embankment surface that will weaken the embankment and can lead to increased erosion. Brush obscures the surface limiting visual inspection, provides a haven for burrowing animals, and retards growth of grass vegetation. Tree and brush growth adjacent to concrete walls and structures may eventually cause damage and should be removed.

It is recommended that stumps of cut trees be removed so vegetation can be established and the surface mowed. Stumps can be removed either by pulling or with machines that grind them down. All woody material should be removed to about 6 inches below the ground surface. The cavity should be filled with well-compacted soil and grass vegetation established. If tree stumps are not removed, they should be cut flush with the surface of the embankment and chemically treated to prevent further growth.

Mowing and Brush Removal

Embankments, areas adjacent to spillway structures, vegetated channels, and other areas associated with a dam require continual maintenance of the vegetative cover. Grass mowing, brush cutting, and removal of woody vegetation (including trees) are necessary for the proper maintenance of a dam. All embankment slopes and vegetated earth spillways should be mowed at least twice a year. Mowing promotes the formation of a sod and gives a neat well kept appearance to the dam. Aesthetics, unobstructed viewing during inspections, maintenance of a non-erodible surface, and discouragement of groundhog habitation are reasons for proper maintenance of the vegetal cover.

Many methods are available for vegetation control. Acceptable methods include the use of weed whips or power brush-cutters and mowers. Chemical spraying to first kill small trees and brush is acceptable if precautions are taken to protect the local environment. Manufacturers recommendations should be followed when using chemical herbicides.

A wide variety of tools, attachments, and power equipment is available for satisfactory maintenance of vegetation. Hand-held brush cutters or weed whips range in weight from about 13 to 28 pounds. Cutting widths range

up to about 21 inches, and there are various cutting blades including nylon string, plastic blades, and metal knife blades. These units can be used to cut grass, brush, woody vegetation up to 4 inches in diameter and can be used on almost any slope.

Hand mowers are available in both push and self-propelled models. Width of cut varies up to a maximum of about 36 inches while maximum cutting height is about 4 inches. Hand mowers can be used safely on many slopes.

Garden and lawn tractors are available from 10 to a maximum of about 20 horsepower. They can be provided with wheels of different widths and with turf or agricultural tires. These type tractors may be equipped with four-wheel drive. Self-leveling units are also available for use on slopes. Power take-off drives are available for attachment to mowers and other accessories. Tractor speeds range to a maximum of about 7 miles per hour. Mower units are normally rotary, but pull-type flail and reel-type units are also available. Cutting height is a maximum of 7 inches and width of cut is from 36 to 60 inches. A garden tractor equipped with a 48-inch mower can mow about 1 acre an hour, depending on the slope and thickness of vegetation.

Large farm tractors are available in engine sizes ranging from 22 horsepower up to 50 horsepower and higher. They are available in low profile models with four-wheel drives, self-leveling units for use on slopes, adjustable front and rear wheel widths, agricultural or turf tires, and power take-off drives for various accessory units. Maximum speeds are around 12 miles per hour.

Mowing units, including rotary, reel, flail, and sickle bar types, are available for the large tractors. The tractor horsepower should be

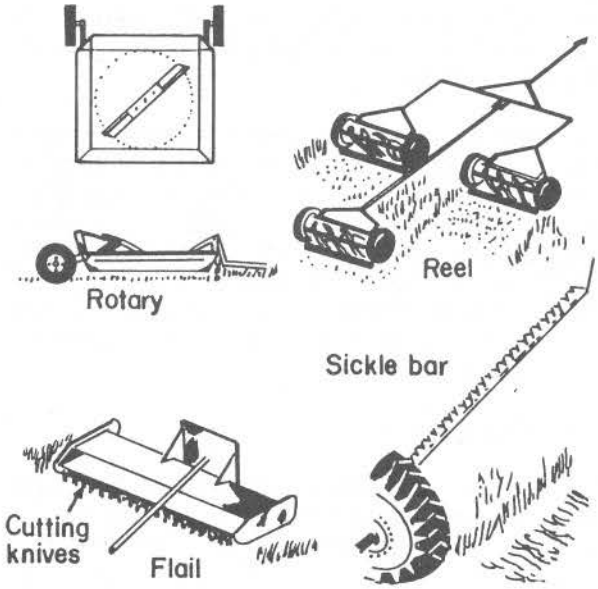

Figure 31 - Mowing units

matched to the mowing unit needed for the job per the manufacturer's recommendations. The garden and farm tractors described in this manual cannot be used safely on slopes steeper than 2 1/2 horizontal to 1 vertical (40% or 21.8° slope). The larger tractors should be obtained with the lowest profile (or center of gravity) necessary for the type of slope to be mowed. Dual wheels or wider tires can be used to increase stability. All of these units should be equipped with safety roll bars designed to support the full weight of the tractor. The following table is a conversion for typical slope terminology:

Slope	% of Grade	Slope Angle
1H:1V	100%	45.0°
1.5H:1V	67%	33.7°
2H:1V	50%	26.6°
2.5H:1V	40%	21.8°
3H:1V	33%	18.4°

Table 1: Available widths and cutting heights.

	Cutting Height	Width of Cut (Single Units)	Width of Cut (Gang Units)
Rotary	1½" to 15"	42" to 84"	15 ft. (Batwing)
Flail	3/4" to 5"	36" to 88"	19 ft. (5 units
Reel	½" to 2 ½"	18" to 30"	11 ft. (5 units)
Sickle Bar	-- --	48" to 108"	

Self-contained mowing units are also available with self-leveling suspension for mowing very steep slopes.

It is important to remember to use the proper equipment for the slope and type of vegetation to be cut, to always follow the manufacturer's recommended safe operation procedures, and not to mow when the vegetation is wet. Mowing should be done horizontally to prevent the formation of ruts aligned with the slope. Ruts can channel runoff and form erosion gullies.

Livestock Control

Livestock should not be allowed to graze on the embankment surface. When the soil is wet, livestock can damage the vegetation and destroy the smooth surface resulting in ponded water or erosion from concentrated runoff. The resulting rough surface is difficult to mow. Cattle also tend to walk in paths killing the vegetation and forming channels for runoff. Livestock paths should be graded, seeded, and mulched. Livestock should be fenced off the dam and spillways.

BURROWING ANIMALS

Rodents such as the groundhog (woodchuck), muskrat, and beaver are attracted to dams and reservoirs and can be quite dangerous to the structural integrity and proper performance of the embankment and spillway. Groundhogs typically burrow into the downstream slope while muskrats and sometimes beavers burrow into the upstream slope from below the water line. Collapse of the burrow can result in a hole in the crest of the dam. Burrows weaken the embankment and can serve as pathways for seepage. Beavers may plug the spillway and raise the reservoir level. Rodent control is essential in preserving a well-maintained dam.

The Groundhog or Woodchuck

The groundhog is the largest member of the squirrel family. Its coarse fur is a grizzled grayish brown with a reddish cast. Typical foods include grasses, clover, alfalfa, soybeans, peas, lettuce, and apples. Breeding takes place during early spring (beginning at the age of 1 year) with an average of four or five young per litter, one litter per year. The average life expectancy is 2 or 3 years with a maximum of 6 years.

Occupied groundhog burrows are easily recognized in the spring due to the groundhog's habit of keeping them "cleaned out." Fresh dirt is generally found at the mouth of active burrows. Half-round mounds and paths leading from the den to nearby fields also help identify inhabited burrows and dens.

When burrowing into an embankment, groundhogs stay above the phreatic surface (saturated zone) to stay dry. The burrow is rarely a single tunnel. It is usually forked, with more than one entrance and with several side passages or rooms from 1 to 12 feet long.

Control methods should be implemented during early spring when active burrows are easy to find, young groundhogs have not scattered, and there is less likelihood of damage to other wildlife. In later summer, fall, and winter, game animals will scurry into groundhog burrows for brief protection and may even take up permanent abode during the period of groundhog hibernation.

Groundhogs can be controlled by using fumigants or by shooting. Fumigation is the most practical method of controlling groundhogs. Around buildings or other high fire hazard areas, shooting may be preferable. Groundhogs will be discouraged from inhabiting the embankment if the vegetal cover is kept mowed. Information about the control of groundhogs may be obtained from the following:

The Missouri Dept. of Conservation
Wildlife Section
P.O. Box 180
Jefferson City, Missouri 65102
314/751-4115

Muskrat

The muskrat is a stocky rodent with a broad head, short legs, small eyes, and rich dark brown fur. Muskrats are chiefly nocturnal. Their principal food includes stems, roots, bulbs, and foliage of aquatic plants. They also feed on snails, mussels, crustaceans, insects, and fish. Usually three to five litters averaging six to eight young per litter, are produced each year. Adult muskrats average 1 foot in length and 3 pounds in weight. The life expectancy is less than 2 years, with a maximum of 4 years. Muskrats can be found wherever there are marshes, swamps, ponds, lakes, and streams having calm or very slowly

Rodent Burrows

Figure 32 - Animal burrow

moving water, with vegetation in the water and along the banks.

Muskrats make their homes by burrowing into the banks of lakes and streams. Their burrows begin from 6 to 18 inches below the water surface and penetrate the embankment on an upward slant. At distances up to 15 feet from the entrance, a dry chamber is hollowed out above the water level. Once a muskrat den is occupied, a rise in the water level will cause the muskrat to dig farther and higher to excavate a new dry chamber. Damage (and the potential for problems) is compounded where groundhogs or other burrowing animals construct their dens in the embankment opposite muskrat dens.

Barriers to prevent burrowing offer the most practical protection to earthen structures. A properly constructed riprap and filter layer will discourage burrowing. The filter and riprap should extend at least 3 feet below the water line. As the muskrat attempts to construct a burrow, the sand and gravel of the filter layer caves in and thus discourages den building. Heavy wire fencing laid flat against the slope and extending above and below the waterline can also be effective. Eliminating or reducing aquatic vegetation along the shoreline will discourage muskrat habitation.

Trapping with steel traps is usually the most practical method of removing muskrats from a pond. Owners should contact the nearest Missouri Department of Conservation, Wildlife Section for regulations concerning trapping.

Eliminating a Burrow

The recommended method of backfilling a burrow on an embankment is mudpacking. This simple, inexpensive method can be accomplished by placing one or two lengths of metal stove or vent pipe in a vertical position over the entrance of the den. After it is certain that the pipe connection to the den does not leak, the mud-pack mixture is poured into the pipe until the burrow and pipe are filled with the earth-water mixture. The pipe is removed and dry earth is tamped into the entrance. The mud-pack is made by adding water to a 90 percent earth and 10 percent cement mixture until a slurry or thin cement consistency is attained. All entrances should be plugged with well-compacted earth and vegetation established. Dens should be eliminated without delay because damage from just one hole can lead to failure of a dam or levee.

Beaver

Beaver will try to plug spillways with their cuttings. Routinely removing the cuttings is one way to alleviate the problem. Another successful remedy is the placement of electrically charged wire or wires around the spillway inlet. Trapping beaver may be done by the owner during the appropriate season; however, the nearest Missouri Department of Conservation, Wildlife Section or state game protector should be contacted first.

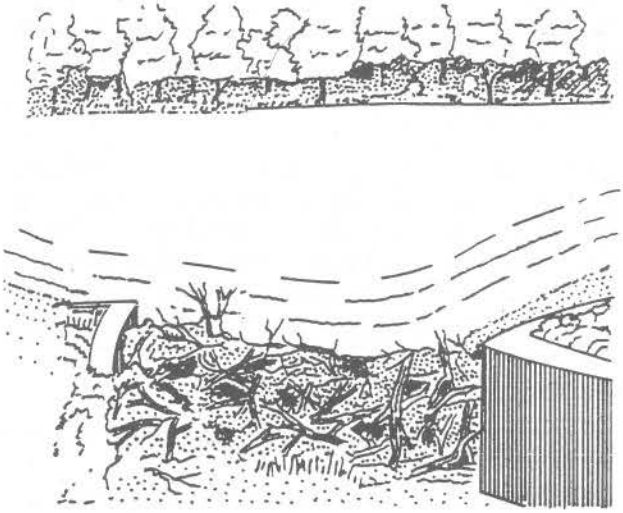

Figure 33 - Beaver dam in spillway

Hunting and Trapping Regulations

Because hunting and trapping rules change from year to year, Department of Conservation, Wildlife Division authorities at one of the following offices should be consulted before taking any action:

HQ, Jefferson City, 314/751-4115
St. Louis Office, 314-726-6800
Kansas City Office, 816/356-2280
Springfield Office, 417/881-5102

RESERVOIR

The reservoir banks should be examined for undercutting and erosion. Depending on the size of the reservoir, a bank slide could displace enough water to overtop the dam; smaller slides could block the spillway or reduce the reservoir capacity.

At many reservoirs around the state, land developers have constructed sewer lines on concrete piers in the reservoir. Due to the steep terrain in the Ozark Region of the state, this method of construction has enabled developers to maintain a gravity sewer system with a minimum of pumping stations and pressurized sewer mains (force mains). Although popular with some developers, this practice is discouraged by the Dam and Reservoir Safety Program because of the tendency for exposed pipes to freeze and break during low reservoir levels. The presence of sewer or water lines in the reservoir presents problems for dam owners who want to lower their reservoirs in the winter for maintenance or to prevent damage to bulkheads, boat docks, and appurtenant structures at the dam.

Dam owners should be aware of their responsibility to obtain flood easements for any upstream land they do not own that would be inundated by backwater during the spillway design flood. Modifications to a dam that involve either raising the water storage elevation or the crest should only be done after consideration of upstream flooding.

MONITORING DEVICES

Various devices such as weirs, piezometers, and settlement monuments are used to monitor earth embankments and concrete gravity structures. These devices can be used to determine if the structure is performing as designed, to detect signs of serious problems, or to provide further information after a problem has been detected. Due to expense, the use of extensive instrumentation to ensure safety is usually limited to large dams where failure would result in loss of life and a great deal of damage. A full-scale monitoring and instrumentation program requires professional design and will not be discussed here.

The following devices can easily be used by owners to monitor their embankments.

V-Notch Weir

The v-notch weir is probably the most commonly used device to measure flow rates of seepage. Effective readings must be taken periodically. The owner should be sure to measure the reservoir elevation, the depth of flow over the weir, and the temperature of the water every time a reading is taken. The depth of flow over the weir should be measured with a ruler located a few inches away from the weir. For ease in taking readings, the bottom of the ruler should be at the same elevation as the notch and should be permanently attached to the weir box. At times, the weirs are neglected after installation and a few good readings become useless for lack of comparative data. Consequently, the v-notch weir itself must be maintained.

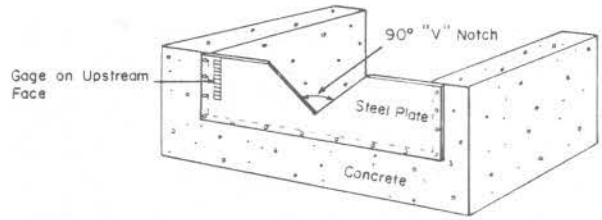

Figure 34 - V-notch weir for monitoring seepage

Flow rates in gallons per minute for uncalibrated weirs and pipe outlets can be measured by timing how long it takes to fill a bucket of known capacity.

Yardstick or Folding Ruler

This portable monitoring device is not only inexpensive but has a number of uses. It can

be used to measure cracks, scarps, erosion gullies, settlement, trees, wet areas, and slab or wall movement. Again, records should be kept of all observations for comparative purposes.

Camera

Photographs which have been dated and labeled provide an excellent record of existing conditions. If taken periodically from the same location, the photographs can be used for comparison. Photographs should be taken during all inspections to supplement written and visual observations. They are valuable in documenting the location and severity of wet areas, erosion, and concrete deterioration.

Piezometers, settlement monuments, observation wells, and inclinometers are often found on large dams and are described briefly. The installation requires professional assistance.

Piezometers

Piezometers are instruments used to measure the water pressure in the embankment and foundation soil and are installed at various levels in a drill hole. The most common type of piezometer encountered on small dams is an open standpipes. Readings are usually taken by measuring the elevation of water in the standpipe. Seepage pressure can be determined from piezometer readings.

Settlement Monuments

Settlement monuments are usually installed along the crest of the dam to check its vertical and horizontal alignments (with known reference points and elevations). Measurements of these monuments must be precise and are obtained using surveying instruments.

Observation Wells

Observation wells can be installed in the embankment or foundation and are used to determine the ground-water level.

Inclinometers

Inclinometers are instruments that are lowered into a vertical casing to measure horizontal deflection. Inclinometers are often used to determine the rate of movement of a slide.

Monitoring by a private owner is usually limited to visual observation. It is very important that the observations are accurate, made periodically, and recorded. An inspection checklist for this purpose has been included at the end of this manual. Owners are encouraged to use photographs with identifying dates and labels as a permanent record to be filed with other dam records.

TAILINGS DAMS

The surface disposal of mine waste in Missouri involves the construction of dams to contain the tailings. Tailings are the material generated by a mining/milling operation and are typically deposited in slurry form in an impoundment. Dams and reservoirs are constructed by the mining industry to form impoundments that retain both the tailings and the mill effluent. These structures are termed *industrial water retention dams* in the Code of State Regulations and are also known as "tailings dams". They have been constructed in the past to store mill wastes resulting from the mining of lead, iron, barite, and coal. Tailings dams can be grouped into two general classes: water retention type dams and raised embankments.

Water retention dams are essentially compacted earth fill dams. This type of dam has been used very little in Missouri due to the suitability of mill tailings for the construction of

Figure 35 - Lead tailings dam

retention structures. Rather than excavate soil to build a dam, it is usually much more cost effective to construct the dam with coarse rock separated at the mill or coarse tailings separated by the hydrocyclone process at the dam site. The finer mill tailings are placed in the reservoir and dam construction progresses as material is generated by the mill. In effect, the embankment is raised in stages. While staged construction of tailings dams is common practice, special consideration must be given to the control of seepage with clay blankets, filters, and drains. A spillway must be provided for all stages and, therefore temporary spillways are constructed.

There are three common methods of constructing tailings dams in stages (see Figure 36). These are referred to as the *upstream method, centerline method, and downstream method* of construction. The selection of the

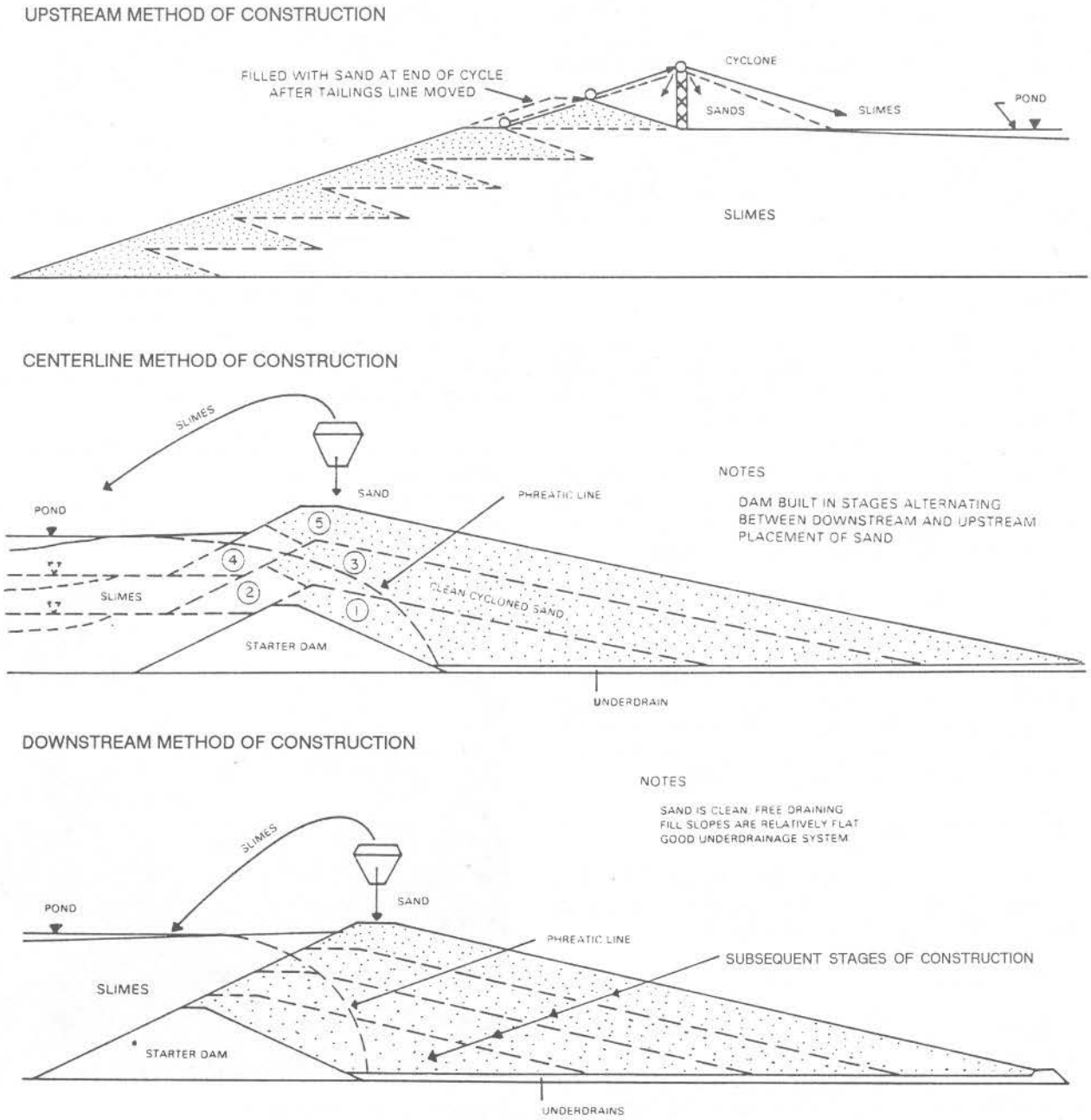

Figure 36 - Methods of tailings dam construction

Figure 37 - Cyclone machine

appropriate method depends upon site conditions, physical and mechanical properties of mill tailings, and the mill production rate. In most cases, the selection of various surface impoundment options and type of embankment construction is based upon cost. The majority of the tailings dams in Missouri were constructed by the centerline method, but several dams were built using the other two methods.

Water retention dams and embankments constructed by the downstream method are suitable for most types of tailings and have good water storage capabilities. If well compacted during construction, they also have good resistance to seismic events and have no restrictions pertaining to how quickly the embankment may be raised. These are definitely the most desirable type of tailings impoundments, but they are also the most expensive to construct because of additional material handling expenses.

The centerline method of construction works best for impounding sands or low plasticity fines; however, this method is not suitable for permanent storage of water. During the operation of this type of dam, the owner should insure that the intake towers, inlets, and decant lines remain unplugged and free flowing to prevent the reservoir elevation from rising and water ponding against the upstream slope of the dam. Dams constructed of coarse mill reject gravels, by the centerline method, should have an impermeable liner on the upstream slope of the dam. The liner should extend to an elevation above the spillway design flood to prevent water from seeping through the upper portion of the dam.

The upstream method of construction should be avoided when constructing permanent structures. As the dam is raised, its foundation becomes the fine mill tailings (slimes) deposited earlier in the reservoir area. The foundation is then subject to consolidation and it develops minimal strength. It is not suitable for the storage of significant amounts of water, it is very susceptible to seismic-stability problems, and problems can develop if the structure is raised too quickly.

Barite tailings dams are constructed of well graded jig gravels. Fine grained clays are hydraulically deposited in the reservoir to seal the upstream slope of the dam and store water for use in the mill. Most barite tailings dams are constructed in upland areas as cross channel dams or ring dikes on hillsides (See Figure 38). After the conclusion of mining operations, barite tailings dams continue to store water. The fine clay tailings slowly drain, but recharge occurs at a rate dictated by the size of the watershed. The well-graded gravels in the dam have been found to be excellent filters for the drainage of the fine clay material in the basin. It is important for the owners of barite tailings dams to monitor the seepage from the toe

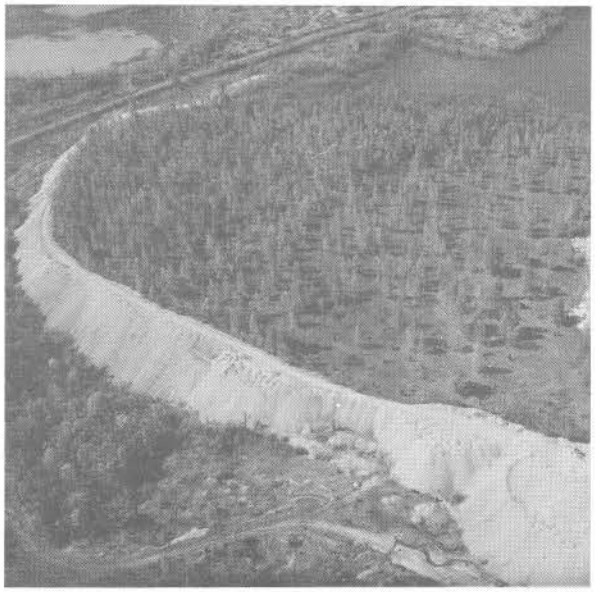

Figure 38 - Barite tailings dam

and keep all spillways clear.

All tailings dams should be regularly monitored to identify slides, sinkholes, and changes in seepage. Seepage rates can be monitored with pipes or v-notch weirs, and the embankment should be inspected regularly for cracks and slides. Dams that are being constructed in stages and that are being used in conjunction with active mills need to be inspected daily. Sinkholes have been known to develop on the downstream slope of a tailings dam very quickly. This problem is caused by incorrectly designed filters and complicated by the noncohesive materials used to construct the dam. Because of the erosive nature of the materials in the dam, the operation of a hydrocyclone and a tailings pipeline must be monitored so that the dam is not damaged by a malfunction or rupture of the pipeline.

Spillways should be located in rock or natural soils as far away as possible from the dam. This is especially important for lead tailings dams, due to the erodibility of the material used to construct the embankments. Spillways should be kept free of debris and steps should be taken to insure that tailings will not flow out through the spillway during frequent rainfall or the design flood. Erodible or fuse-plug spillways are not allowed in the staged construction of tailings dams because they can result in the release of stored water or tailings.

At the conclusion of mining operations, the tailings dam will become inactive. According to Missouri law, the owner will not be released from registration permit requirements because tailings are defined as water. The long-term mass stability, erosion stability, and hydraulic capacity of the dam must therefore be addressed. Maintenance and operation plans are necessary and must be implemented by the owner to take case of these concerns.

Lead tailings dams can be revegetated for long-term erosion stability; however, this can be an expensive process. Revegetation of Missouri tailings dams has been attempted by constructing a clay blanket on the crest and slopes of the dam. The thickness of the clay and the type of vegetation to be planted on the dam depend on soil characteristics such as texture, fertility, and toxicity. Texture refers to the grain size of the soil as well as the degree of aggregation of individual particles. Fine-textured soils may hold excessive moisture when wet or may be compact when dry, and thereby inhibit root penetration. Coarse soils, such as those used to construct tailings dam, may not be able to hold sufficient moisture to sustain plants, even in the presence of adequate rainfall. Soil fertility refers to nutrients required for plant growth, including nitrogen, potassium, and phosphorous, as well as the necessary bacteria dn fungi. Toxicity of the growth medium will stunt or kill developing plants. While heavy metals such as iron, manganese, and zinc are necessary in very small quantities for healthy plant growth, the presence of the same constituents in higher concentrations may slow or preclude plant development.

The revegetation of lead tailings dams has met with mixed results primarily because of problems caused by deposition of windborne fine tailings on the vegetation established on the clay. In some cases, fences have been constructed to control wind erosion of fine tailings but that method is very expensive and is not totally effective. In conjunction with revegetation of the dam, reclamation of the reservoir are is also necessary.

Historically in Missouri, hydrologically induced failures have been the major cause of mass instability of inactive tailings dams. Wide beaches of fine materials on the upstream side of tailings dams are necessary to keep the reservoir water away from the structure. This will lower the phreatic surface in the dam, resulting in decreased seepage rates and an increase in the overall stability. Accumulation of runoff water in an impoundment, in addition to raising the possibility of slope or seismic instability, can cause direct impoundment failure by overtopping or by erosion at the embankment toe; therefore, maintenance of spillways, ditches, pipes, culverts, and inlets is extremely important. Tailings are notoriously susceptible to gullying by water-runoff erosion and grading is frequently necessary to repair eroded areas. A maintenance and operation plan is therefore a very important part of the process of maintaining a safe tailings dam and is required before a registration permit or safety permit will be issued by the Missouri Dam and Reservoir Safety Council.

VII OPERATION

OPERATION PLANS

In order to provide operation controls for reservoir levels, it is important for owners to understand how the watershed above the dam works. A watershed is the area of land that drains into the reservoir. Within a watershed, precipitation will infiltrate into the ground, move as surface runoff, evaporate, and transpire. The dam owner should recognize that the water that flows into a reservoir is dependent on precipitation as well as soil types, land use, topography, and other factors. Springs are very common in certain parts of Missouri and new dam owners should contact the Missouri Department of Natural Resources, Division of Geology and Land Survey for information on the geology of their watersheds. Rapid flows into an impoundment can result in a dramatic rise of the reservoir. High inflows are usually the result of heavy precipitation within a watershed. However, other combinations of climatic and ground conditions can cause large amounts of runoff. An example would be moderate rain on frozen ground, combined with snowmelt. In this case, there would be little or no infiltration and nearly all the rainfall would move as surface runoff.

One of the best ways for a dam owner to understand his watershed is by compiling a history of precipitation, ground conditions, and corresponding spillway flows. Over time, the owner will become aware of the length of time between rainfall and flow increases at the dam.

An owner's response to heavy rainfall will be determined by the operation plan that is developed with the watershed information. To pass flood flows, critical spillway equipment must be operable and well maintained.

In developing an operation plan, the owner should be aware that log jams, debris, and ice buildup can block a spillway and prevent it from passing the flood flow.

The operation plan should be in writing in order to provide the owner with a logical set of instructions to follow. If well organized, this information can easily be passed on to future owners. The operation plan should provide for limited access to spillway controls, and locks on all fencing, valves, and mechanical equipment.

RESERVOIR LEVELS

The operation plan should specify how and when to release water in normal and flood times, what equipment is needed, and who is responsible. It must take into account that a

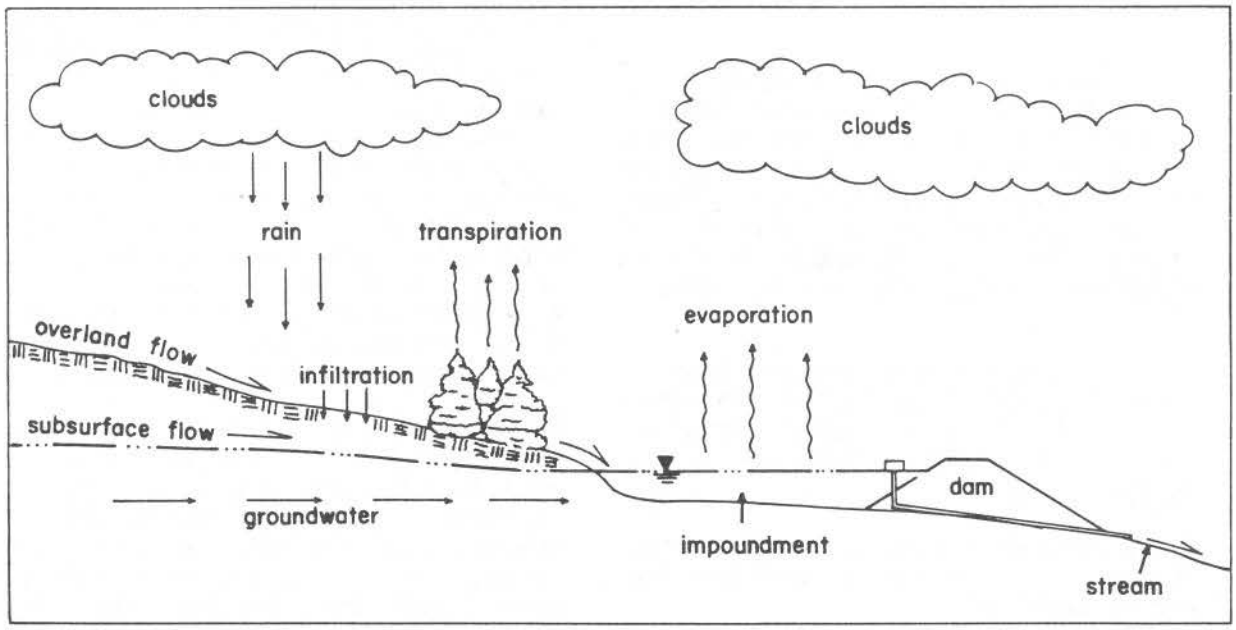

Figure 39 - Hydrologic cycle

minimum flow release may be required for downstream users, as well as fishery and wildlife-habitat protection. These minimum flows should be determined in cooperation with downstream water users, and in some cases, the Missouri Department of Conservation.

Impoundment levels required to protect upstream users should also be included. This may require that minimum, normal, and maximum impoundment levels be established. If the reservoir level is raised, flowage rights or easements must be checked.

Any drawdown of the reservoir will require detailed calculations of the amount of flow that can be released from the structure without causing downstream flooding. Investigating silt load in the impoundment and analyzing its potential for downstream damages should be addressed.

Reservoir pool levels are often controlled by spillway gates, lake drain and release structures, and flashboards. Listed below are conditions or instances in which the pool level might be permanently or temporarily adjusted:

1) A problem develops that requires the pool to be lowered. Drawdown is temporary until the problem is solved.

2) Water released to the downstream channel supplements streamflow during dry conditions. This may temporarily lower the lake level.

3) Water-supply reservoir levels will fluctuate according to the service area's demand for water. Flashboards are sometimes used to permanently or temporarily raise the pool level of water-supply reservoirs. Flashboards should not be installed or allowed unless there is sufficient freeboard remaining to safely pass the design flood.

4) The reservoir level is drawn down to facilitate repair of boat docks, to retard growth of aquatic vegetation along the shoreline, and to allow additional storage for spring runoff.

5) Pool levels are sometimes adjusted for recreation, hydropower, or waterflow and fish management.

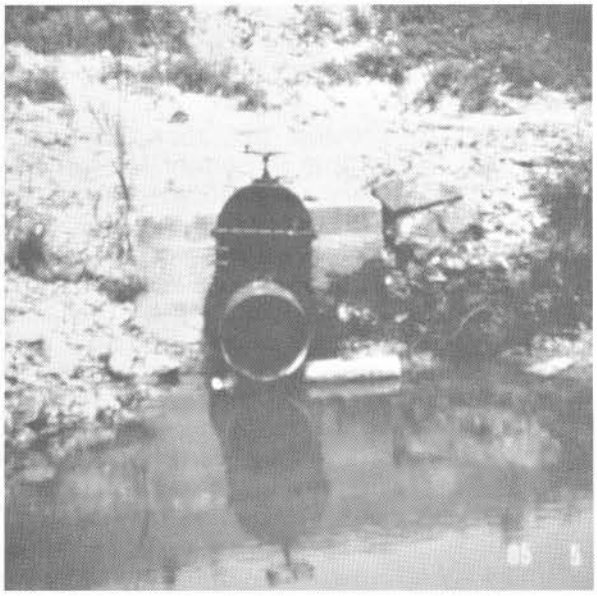

Figure 40 - Gate valve on lake drawdown pipe

LAKE DRAINS

The lake drain should always be operable so that the pool level can be drawn down in case of an emergency or for necessary repair. Lake drain valves or gates that have not been operated for a long time present a special problem for owners. If the valve cannot be closed after it is opened, the impoundment could be completely drained. An uncontrolled and rapid drawdown could also induce more serious problems such as slides in the saturated upstream slope of the embankment. Drawdown rates should not exceed 1 foot per week for slopes of clay or silt material, except for emergency situations. Very flat slops or slopes with free draining upstream zones can withstand more rapid drawdown rates. Large discharges could also cause downstream flooding; therefore, before operating a valve or gate, it should be inspected and all appropriate parts lubricated and repaired. It is also prudent to advise downstream residents of large or prolonged discharges.

To test a valve or gate without lowering the lake, the drain inlet upstream from the valve must be physically blocked. Some drain structures have been designed with this capability and have dual valves or gates, or slots for stoplogs (sometimes called bulkheads) located upstream of the drain valve. Divers

can be hired to inspect the drain inlet and may be able to construct a temporary block at the inlet for testing purposes.

Other problems may be encountered when operating the lake drain. Sediment can build up and block the drain inlet. Debris can be carried into the valve chamber, thereby hindering its function if an effective trashrack is not present. The potential that these problems will occur is greatly reduced if the valve or gate is operated and maintained periodically. The gate or valve controlling the lake drain should be operated from the fully closed to fully open position at least twice a year. It is preferable that the drain be operated four times a year. Early detection of equipment problems or breakdowns and confidence in equipment operability are benefits of periodic operation.

The Missouri Dam and Reservoir Safety Program recommends that drain valves for all new or reconstructed dams be located upstream from the centerline of the dam. Many older dams have drains with valves at the downstream end. This results in the entire conduit being under the constant pressure of the reservoir when the valve is closed. If a leak should develop in that portion of the conduit within the embankment, saturation, erosion, and possibly failure of the embankment could occur in a short period of time. A depression in the soil surface over the pipe may be a sign that soil is being removed from around the pipe. Older structures should be monitored closely and owners should plan to relocate the valve upstream or install a new drain structure. Inspectors should closely examine the drain outlet for signs of possible problems.

Figure 41 - Sluice gate

MECHANICAL EQUIPMENT

Mechanical equipment includes spillway gates, sluice gates or valves for lake drains or water supply pipes, stoplogs, sump pumps, flashboards, relief wells, emergency power sources, siphons, and other devices. All mechanical and associated electrical equipment should be operated at least once a year and preferably more often. The annual test should be conducted through the full operating range under actual operating conditions to determine that the equipment performs satisfactorily. Operating instructions should be checked for clarity and maintained in a secure, but readily accessible location. Each operating device should be permanently marked for easy identification. All operating equipment should be accessible. All equipment controls should be checked for proper security to prevent vandalism.

SEDIMENTATION AND DREDGING

Erosion and sedimentation are natural processes in which soil particles are detached from the earth by raindrops or flowing water and carried by stream flow. Stream velocity, among other factors, determines the capacity of streams to transport sediments. When streams enter lakes, their velocities suddenly drop and the sediment load is deposited on the lake bottom. Typically, about 90 percent of the sediment load carried by incoming streams is deposited in a lake.

Sedimentation occurs in every lake, regardless of whether the lake is natural or created by a dam. Sedimentation rates vary widely and depend on many watershed factors. Among these are soil type, land cover, land slope, land use, stream slope, size of watershed, total annual precipitation, number and intensity of severe storm events, material in the streambed, and volume of the lake with respect to size of the drainage area. In Missouri, most of the sediment enters lakes and reservoirs during a few large flood events that occur each year. Sediment deposits first become apparent when deltas build up at the

mouths of streams entering the lake. Aquatic vegetation, such as cattails and lily pads, soon develop in the shallow water over these deltas. As sediment deposition continues, the delta will rise above the water surface.

The best way to avoid sedimentation problems is to reduce erosion in the watershed area. Because most dam owners do not control the land in the watershed, other means must be found to minimize the effects of sedimentation. One way is by dredging. However, this is expensive and will eventually have to be repeated because the sedimentation process never stops. Disposal of the dredged material is often a problem. Under certain conditions, dredging and disposing of dredged material in a lake or adjacent to a stream requires a permit from the U.S. Army Corps of Engineers. Before undertaking such work, the owner should check with the appropriate District Office of the Corps of Engineers.

One commonly used plan for dredging is to create a relatively narrow channel through the delta and into deeper water. Flow velocities in the narrow channel remain high enough to carry sediment particles into deeper water before they are deposited. The narrow channel is created by placing dredged material along the sides of the channel to build peninsulas. The location and shape of the peninsulas will depend on the configuration of the lake at the point the stream enters. This process will eventually have to be repeated as deposits build in the channel and create new deposition areas.

Another way to control sedimentation is to lower the lake during the winter and early spring when many of the larger floods occur. Sediments will then be carried farther into the lake and deposited several feet below the normal pool. Periodically opening the drain valve will help keep sediment from obstructing or burying the drain inlet.

For ponds with smaller drainage areas, vegetated strips around the pond will act as filters and trap much of the sediment. These are especially effective for ponds where much of the runoff enters as sheet flow rather than flow from small streams.

Many private landowners ask if financial assistance is available for removing sediment from their lake. As of the date of this publication, no state or federal funds are available to private landowners for this purpose.

VANDALISM

Vandalism is a common problem for all dam owners. Particularly susceptible to damage are the vegetated surfaces of the embankment, mechanical equipment, manhole covers, and rock riprap. Every precaution should be taken to limit access to the dam by unauthorized persons and vehicles.

Dirt bikes (motorcycles), off-road-vehicles (ORV's), and four-wheel drive vehicles can severely damage the vegetation on embankments. Worn areas can lead to erosion and more serious problems. Constructed barriers such as fences, gates, and cables strung between poles are effective ways to limit access of these vehicles to the dam. A highway metal guardrail constructed immediately adjacent to the toe of the downstream slope is an excellent means for keeping vehicles off embankments. However, this may interfere with the operation of mowing equipment.

Mechanical equipment and its associated control mechanisms should be protected. Buildings containing mechanical equipment should be sturdy, have protected windows and heavy-duty doors, and should be secured with deadbolt locks or padlocks. Detachable controls such as handles and wheels should

Figure 42 - Locked valve

Figure 43 - Riprap on upstream slope

be removed when not is use and stored inside. Other controls should be secured with locks and heavy chains, where possible. Manhole covers are subject to removal and are often thrown into the lake or spillway by vandals.

Rock used as riprap around dams is occasionally thrown into the lake, spillways, stilling basins, pipe spillway risers, and elsewhere. Riprap is sometimes moved by fishermen to form benches. The best way to prevent this abuse is to use rock too large and heavy to move easily or to slush grout the riprap. Otherwise, the rock must be constantly replenished and other damages repaired.

Owners should be aware of their responsibility for public safety, including the safety of people not authorized to use the facility. "No Trespassing" signs should be posted on fences and warning signs should be erected around dangerous areas. Liability insurance can be purchased to protect the owner in the event of accidents.

RECORD KEEPING

Operation of a dam should include keeping accurate records of the following:

1)*Observations* - All observations should be recorded. Of particular importance is the periodic observation of existing seepage to detect any changes. Photographs are valuable for recording observations and changes.

2) *Maintenance* - Written records of maintenance and major repairs are important. These records should be kept on file and reviewed during periodic safety evaluations of the dam.

3) *Rainfall and Pool Levels* - A record of the date, hour, and maximum elevation of extreme high-water events and the associated rainfall is especially helpful in evaluating the performance of the dam and its spillway system. Rain gages are available at any local farm or garden store. Lake-level staff gates can be installed in the reservoir or measurement numbers can be painted on existing structures in the pool area. Reservoir records are especially important for all water supply lakes that have widely fluctuating water levels.

4) *Drawdown* - A record should be kept of the amount, rate, and reason for pool-level drawdown.

Figure 44 - Completing dam inspection checklists

5) *Other Operation Procedures* - A complete listing of operational procedures should be maintained.

Suggested checklists are included at the back of this manual for recording inspection observations and maintenance, operation, rainfall, and pool level events.

The owner is encouraged to maintain a complete and up-to-date set of plans and specifications ("as-built" drawings) for the dam, which should show all changes made over time. Knowing how a dam, its spillways, and other appurtenances were constructed and modified is very helpful in diagnosing problems.

CHECKLISTS

Periodic inspection of dams is extremely important. Owners are encouraged to make a thorough visual inspection of their dams at least twice a year, once in the summer and once in the winter, and to have their dams inspected by a registered professional engineer at least once every 5 years. A closer inspection of the embankment surface can usually be made during the winter months when the vegetal cover is dormant and during the summer immediately after mowing. Throughout this manual, items to look for during inspection have been emphasized.

Included in this section are suggested forms to record inspection observations, and operation, maintenance, rainfall, and pool level records. The inspection forms identify common problems for each area inspected.

The first set of forms is for recording inspection observations. The forms are primarily for earth dams but can be modified slightly for concrete or tailings dams. The second form is for recording operation, maintenance, rainfall, and pool level events.

OWNER INSPECTION CHECKLIST

NAME OF DAM: _____ DATE INSPECTED: _____
COUNTY: _____ WEATHER: _____
I.D. NO.: _____ TEMPERATURE: _____
DOWNSTREAM ENV. ZONE: _____ POOL ELEVATION: _____
TYPE OF DAM: _____ PERSON MAKING INSPECTION: _____

Directions: Mark an "X" in the YES or NO column. If an item does not apply, write "NA" in the REMARKS column. (If possible, identify any changes since the last inspection under REMARKS)

ITEM	YES	NO	REMARKS
1. CREST			
a. Any visual settlements?			
b. Misalignment?			
c. Cracking?			
2. UPSTREAM SLOPE			
a. Adequate grass cover?			
b. Any erosion?			
c. Are trees growing on slope?			
d. Longitudinal cracks?			
e. Transverse cracks?			
f. Adequate riprap protection?			
g. Any stone deterioration?			
h. Visual depressions or bulges?			
i. Visual settlements?			
j. Debris or trash present?			
3. DOWNSTREAM SLOPE			
a. Adequate grass cover?			
b. Any erosion?			
c. Are trees growing on slope?			
d. Longitudinal cracks?			
e. Transverse cracks?			
f. Visual depressions or bulges?			
g. Visual settlements?			
h. Is the toe drain dry?			
i. Are the relief wells flowing?			
j. Are boils present at the toe?			
k. Is seepage present?			
l. Soft or spongy zones present?			

OWNER INSPECTION CHECKLIST (cont.)			
ITEM	YES	NO	REMARKS
m. Are foundation drainpipes:			
(1) Broken, bent, or missing?			
(2) Corroded or rusted?			
(3) Obstructed?			
(4) Is discharge carrying sediment?			
4. ABUTMENT CONTACTS			
a. Any erosion?			
b. Visual differential movement?			
c. Any cracks noted?			
d. Is seepage present?			
5. PRINCIPAL SPILLWAY INLET			
a. Do concrete surfaces show:			
(1) Spalling?			
(2) Cracking?			
(3) Erosion?			
(4) Scaling?			
(5) Exposed reinforcement?			
(6) Other?			
b. Do the joints show:			
(1) Displacement or offset?			
(2) Loss of joint material?			
(3) Leakage?			
c. Metal appurtenances?			
(1) Corrosion present?			
(2) Breakage present?			
(3) Anchor system secure?			
d. Trashrack operational?			
6. PRINCIPAL SPILLWAY CONDUIT			
a. Is the conduit concrete?			
b. Do concrete surfaces show:			
(1) Spalling?			
(2) Cracking?			
(3) Erosion?			
(4) Scaling?			
(5) Exposed reinforcement?			
(6) Other?			

OWNER INSPECTION CHECKLIST (cont.)			
ITEM	YES	NO	REMARKS
c. Do the joints show:			
(1) Displacement or offset?			
(2) Loss of joint material?			
(3) Leakage?			
d. Is the conduit metal?			
(1) Corrosion present?			
(2) Protective coatings adequate?			
(3) Is the conduit misaligned?			
e. Is there seepage around the conduit?			
7. STILLING BASIN			
a. Do concrete surfaces show:			
(1) Spalling?			
(2) Cracking?			
(3) Erosion?			
(4) Scaling?			
(5) Exposed reinforcement?			
(6) Other?			
b. Do the joints show:			
(1) Displacement or offset?			
(2) Loss of joint material?			
(3) Leakage?			
c. Do the energy dissipators and riprap show:			
(1) Signs of deterioration?			
(2) Are they covered with debris?			
(3) Other?			
d. Is the channel:			
(1) Eroding or backcutting?			
(2) Sloughing?			
(3) Obstructed?			
e. Is released water:			
(1) Undercutting the outlet?			
(2) Eroding the embankment?			
8. EMERGENCY SPILLWAY			
a. Does spillway concrete show:			
(1) Spalling?			
(2) Cracking?			
(3) Erosion?			

OWNER INSPECTION CHECKLIST (cont.)

ITEM	YES	NO	REMARKS
(4) Scaling?			
(5) Exposed reinforcement?			
(6) Other?			
b. Do the joints show:			
(1) Displacement or offset?			
(2) Loss of joint material?			
(3) Leakage?			
c. Is the spillway in rock or soil?			
(1) Are slopes eroding?			
(2) Are slopes sloughing?			
(3) Other?			
d. Is the discharge channel:			
(1) Eroding or backcutting?			
(2) Obstructed?			
(3) Is vegetative cover adequate?			
e. Has released water:			
(1) Eroded the embankment?			
(2) Undercut the outlet?			
(3) Other?			
f. Is weir in good condition?			
9. GATES			
a. Are the flood gates and valves:			
(1) Located upstream and downstream?			
(2) Broken or bent?			
(3) Corroded or rusted?			
(4) Periodically maintained?			
(5) Operational?			
(6) Date last operated.			
b. Is there a low-level gate?			
c. Is the low-level gate operational?			
10. RESERVOIR CONTROL			
a. Recent upstream development?			
b. Slides in reservoir area?			
c. Change in reservoir operation?			
d. Large impoundment upstream?			
11. INSTRUMENTATION			
a. List types of instrumentation.			

OWNER INSPECTION CHECKLIST (cont.)			
ITEM	YES	NO	REMARKS
b. In good condition?			
c. Read periodically?			
d. Is data available?			
12. AREA DOWNSTREAM			
a. Recent downstream development?			
b. Seepage or wetness?			
13. OTHER COMMENTS:			

This dam was inspected by: _____

OPERATION, MAINTENANCE, RAINFALL & POOL LEVEL RECORDS

NAME OF DAM _____

NORMAL POOL ELEVATION _____

DATE	TIME	RAIN (inches)	POOL LEVEL	WEATHER CONDITIONS	GENERAL OBSERVATIONS OR COMMENTS	RECORDED BY

DATE	MAINTENANCE PERFORMED	COMMENTS	RECORDED BY

DATE	EQUIPMENT OPERATED	COMMENTS	RECORDED BY

FLOW AMOUNTS					WEATHER & COMMENTS	RECORDED BY
DATE	Left Toe Drain	Right Toe Drain	Weirs	Other		

GLOSSARY

Abutment - That part of the valley side against which the dam is constructed. Right and left abutments are those on respective sides of an observer looking downstream.

Anti-seepage collar - A projecting collar of concrete or other material built around the outside of a tunnel or conduit, under an embankment dam, to reduce the seepage potential along the outer surface of the conduit.

Appurtenances - The associated works of a dam other than the embankment or main impoundment structure.

Arch dam - A concrete or masonry dam that is curved in plan to transmit the major part of the water load to the abutments.

As-built drawings - Plans or drawings portraying the actual dimensions and conditions of a dam, dike, or levee as it was built. Field conditions and material availability during construction often require changes from the original design drawings.

Beaching - The removal by wave action of a portion of the upstream (reservoir) side of the embankment and the resultant deposition of this material farther down the slope. Such deposition creates a relatively flat beach area.

Berm - A horizontal step or bench in the slope of an embankment.

Blanket Drain - A drainage layer placed directly over the foundation material.

Boil - A disturbance in the surface layer of soil caused by water escaping under pressure from behind a water-retaining structure such as a dam or levee. The boil may be accompanied by deposition of soil particles (usually sand) in the form of a conical-shaped mound (miniature "volcano") around the area where the water escapes.

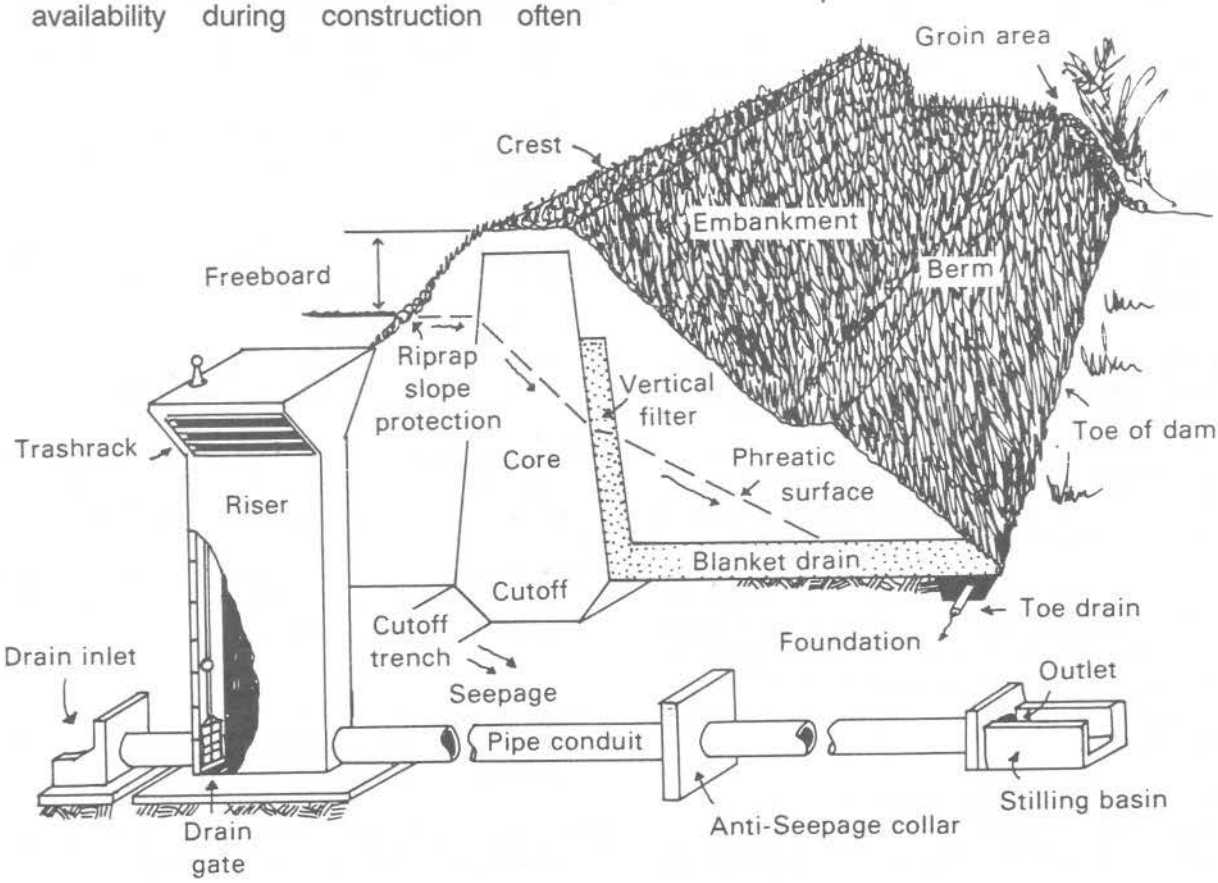

Figure 45 - Cross-section of a dam

Breach - A breakgap, or opening in a dam which releases impoundment water.

Cavitation - Water on hydraulic structures where a high hydraulic gradient is present. Cavitation is caused by the abrupt change in direction and velocity of the water so the pressure at some points is reduced to the vapor pressure and vapor pockets are created. These pockets collapse with great impact when they enter areas of higher pressure, producing very high impact pressures over small areas, which eventually cause pits and holes in the surface. Noises and vibrations may be evident during high flows.

Conduit - A closed channel to convey the discharge through or under a dam.

Construction joint - The interface between two successive placements of concrete where bonding, not permanent separation, is intended.

Contraction joint - A joint constructed such that shrinkage of the concrete would cause a crack.

Core - A zone of material of low permeability, the purpose of which is to reduce the quantity of seepage through the dam.

Core wall - A wall of substantial thickness built of impervious materials, usually of concrete or asphaltic concrete, in the body of an embankment to prevent leakage.

Corrosion - The chemical attack on a metal by its environment. Corrosion is a reaction in which metal is oxidized.

Crest length - The developed length of the top of the dam. Spillways excavated apart from the dam are not included.

Cutoff - A relatively impervious barrier of soil, concrete, or steel constructed either to minimize the flow of water through pervious or weathered zones of the foundation, or to direct flow around such zones.

Cutoff trench - The excavation later to be filled with impervious material so as to form the cutoff. The term is sometimes used incorrectly to describe the cutoff itself.

Dam - A barrier built across a watercourse for impounding or diverting the flow of water. Includes structures built to retain or impound wastes from mining operations.

Dike - See Levee.

Distress - A condition of severe stress, strain, or deterioration, indicating possible or potential failure.

Drainage well or relief well - Vertical wells or boreholes downstream of, or in the downstream berm of, an embankment to collect and control seepage through or under the dam and so reduce water pressure. A line of such wells forms a drainage curtain.

Drawdown - The resultant lowering of water-surface level due to release of water from the reservoir.

Embankment - Fill material, usually earth or rock, placed with sloping sides and usually longer than high.

Failure - An incident resulting in the uncontrolled release of water from an operating dam.

Filter - A bank or zone of granular material that is incorporated in a dam and is graded (either naturally or by selection) to allow seepage to flow across or down the filter without causing the migration of material from zones adjacent to the filter.

Finger drains - A series of parallel drains of narrow width to convey seepage to the downstream toe of the embankment.

Flashboards - Length of timber, concrete, or steel placed on the crest of a spillway to raise the reservoir level.

Flood plain - An area adjoining a body of water or natural stream that has been or may be covered by flood water.

Foundation of dam - The natural material on which the dam structure is placed.

Freeboard - The vertical dimension between the crest of the dam at its lowest point and the reservoir water surface.

Fuse plug spillway - A form of auxiliary or emergency spillway comprised of a low embankment or natural saddle across the spillway channel. It is designed to be overtopped and eroded away during very rare and exceptionally large floods.

Gabion - A hollow cage or basket, usually of heavy wire, filled with stones or rock and used as a revetment or other protective device to sustain a wall or channel.

Gravity dam - A dam constructed of concrete or masonry, which relies on its weight for stability.

Groin area - The area at the intersection of either the upstream or downstream slope of an embankment and the valley wall or abutment.

Grout - A thin cement or chemical mortar used to fill voids, fractures, or joints in masonry, rock, sand and gravel, and other materials. As a verb, it refers to filling voids with grout.

Homogeneous earthfill - An embankment-type construction of more or less uniform earth materials throughout, except for possible inclusion of internal drains or blanket drains. The term is used to differentiate from a zoned earthfill embankment.

Inundation map - A map delineating the area that would be inundated in the event of a dam failure.

Leakage - Uncontrolled loss of water by flow through a hole or crack.

Left abutment - The abutment on the left-hand side of an observer when looking downstream.

Levee (or dike) - Any artificial barrier, together with appurtenant works, that will divert or restrain the flow of a stream or other body of water for the purpose of protecting an area from inundation by flood waters.

Low-level outlet - A low-level reservoir outlet, generally used for lowering reservoir water level or scouring sediment.

Outlet - An opening through which water can be freely discharged from a reservoir to the stream.

Phreatic surface - The upper surface of seepage in an embankment. All the soil below this surface will be saturated when the steady-state seepage condition has been reached.

Piping - Progressive erosion and removal of soil by concentrated seepage flows through a dam, dike, or levee, its foundation, or its abutments. As material is eroded, the area of the "pipe" increases and the quantity and velocity of flow increase; these changes in turn result in the erosion of more material. The process continues at a progressively faster rate. Dam failure can result if the piping cannot be brought under control.

Pore pressure - The internal cellular pressure of a fluid (air and/or water) within the voids of a mass of soil, rock, or concrete.

Reservoir - An artificial impoundment or potential impoundment created by a dam.

Right abutment - The abutment on the right-hand side of an observer looking downstream.

Riprap - A layer of large stone, broken rock, or precast blocks placed in random fashion on the slope of an embankment dam, on a reservoir shore, or in a channel as a protection against flows and wave and ice action.

Rockfill dam - An embankment dam, normally with a central clay core, in which more than 50 percent of the total volume comprises compacted or dumped pervious natural or crushed rock.

Scarp - The nearly vertical, exposed earth surface created at the upper edge of a slide or a beached area, along the upstream slope.

Seepage - The slow percolation of water through a dam, its foundation, or the abutment. A small amount of seepage

will normally occur in any dam or embankment that retains water.

Silt/sediment - Soil particles and debris in an impoundment.

Slide - The movement of a mass of earth or tailings down a slope. In embankments and abutments, this involves the separation of a portion of the slope from the surrounding material.

Slope protection - The protection of the embankment slope against wave action and erosion.

Slough - The separation from the surrounding material and downhill movement of a small portion of the slope. Usually a slough refers to a shallow earth slide.

Spalling - Breaking (or erosion) of small fragments from the surface of concrete, masonry, or stone under the action of weather or abrasive forces.

Spillway - A structure over or through which flood flows are discharged. If the flow is controlled by gates, it is considered a controlled spillway; if the elevation of the spillway crest is the only control, it is considered an uncontrolled spillway.

Stilling basin - An energy-dissipating device at the outlet of a spillway to dissipate the high-velocity (energy) of the flowing water, in order to protect the spillway structure and avoid serious erosion of the outlet channel and subsequent undermining.

Stoplogs - Large logs, timbers, or steel beams placed on top of each other with their ends held in guides on each side of a channel or conduit, to provide an inexpensive and easily handled means of closure.

Structural joint - A joint constructed where movement of a part of a structure, due to temperature or moisture variations, settlement, or any other cause, would result in harmful displacement of adjoining structural components.

Toe of dam - The junction of a dam with the old creek bed or valley bottom.

Training berm - A berm built to confine or guide the flow of water.

Trashrack - A structure of metal or reinforced concrete bars located at the intake of a conduit inlet or waterway to prevent entrance of floating or submerged debris of a certain minimum size and larger.

Uplift - The upward pressure in the pores of a material (internal cellular pressure) or on the base of a structure.

Upstream blanket - An impervious blanket placed on the reservoir floor upstream of a dam. In the case of an embankment, the blanket may be connected to the impermeable zone of the embankment.

Vertical or sloping filter - A filter placed more or less vertically that extends longitudinally through an embankment to intercept seepage flows and prevent them from removing fine soils from the embankment. The filter often has vertical or sloping drainage zones and is normally connected to the blanket drain. It is sometimes called a chimney drain.

Weir - A type of spillway in which flow is constricted and caused to fall over a crest. Sometimes specially designed weirs are used to measure flow amounts. Types of weirs include "broad-crested weir," "ogee weir," and "v-notch weir."

Zoned earthfill - An earthfill-type embankment, the cross section of which is composed of zones of selected materials having different degrees of porosity, permeability, and density.

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