Small Earthen Dam Construction

A Guidebook for Planning and Construction of Small Earthen Embankments

Montana Department of Natural Resource and Conservation
Water Resources Division
Dam Safety Program

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> If anyone be too lazy to keep his dam in proper condition, and does not keep it so; if then the dam breaks and all the fields are flooded, then shall he in whose dam the break occurred be sold for money and the money shall replace the corn which he has caused to be ruined.
>
> Code of Hammurabi, Section 53 (1760 B.C.)

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Disclaimer

This guidebook describes some of the concepts and techniques for planning, designing, constructing, operating, and maintaining earthen embankment dams. Any dam is a significant undertaking, with inherent risks of environmental damage, partial or complete failure, and the potential for property damage and loss of life, with attendant liabilities for the dam engineer, builder, owner, operator, and landowner. **Do not depend solely on information in this book – it is not a substitute for licensed engineering.**

There are no warranties, either expressed or implied, that this book contains accurate, complete, and/or reliable information. Use of this book in no way removes or reduces your assumption of the risks of designing, constructing, operating, and maintaining a dam.

INTRODUCTION

Are you building a small dam or dike? This simple guide will help you consider the critical components necessary to properly build an earth dam that is an asset rather than a liability. The guide is not intended to be a design manual, nor a reference for standards. Rather, the goal of the guide is to present the do's and don'ts of small dam construction, and to alert you to areas of special concern.

Dams are high-risk structures with the capability of causing a lot of damage in the event of a failure. The result of a failure is a loss of the project and property damage as well as a threat to public safety.

Failed Lincoln County embankment dam.

Dams fail due to a variety of reasons. Many fail from overtopping as a result of a rainstorm. Another main cause of failure is internal erosion of the dam from excessive seepage through the embankment. Although less common, dams have been known to fail when seepage flows through rodent holes or when trees on the dam blow over.

Downstream damage from failure of small dam in Lincoln County.

During early planning stages of your project, you should examine what lies downstream. If a failure of the dam could harm anyone, or cause extensive property damage, the services of a qualified engineer will be needed for the design, construction supervision, and periodic inspections of the dam.

The keys to a safe, durable dam are proper planning, design, construction, and maintenance.

GUIDE CONTENTS

This guide is divided into seven sections. The first section of this guide deals with **project planning and site preparation**. What permits do I need? Where should I stockpile borrow material? Will the reservoir hold water? Where should I place the spillway? This could very well be the most important phase of the project. A well thought out plan and proper site preparation can prevent costly mistakes!

The second section deals with the nitty-gritty details of **constructing the embankment**. There are many little tricks and techniques available to help build a strong, safe embankment.

All dams must have the ability to safely release water, requiring some kind of conduit and gate system, commonly referred to as the "outlet works." The third section of this guide describes how **gates and conduits** are used in dams.

Earth dams are not very resistant to overtopping by the reservoir. Rainstorms can generate high inflows to the reservoir. A spillway is required to pass the high inflows safely past the dam. The fourth section describes the different types of **spillways** and discusses their importance.

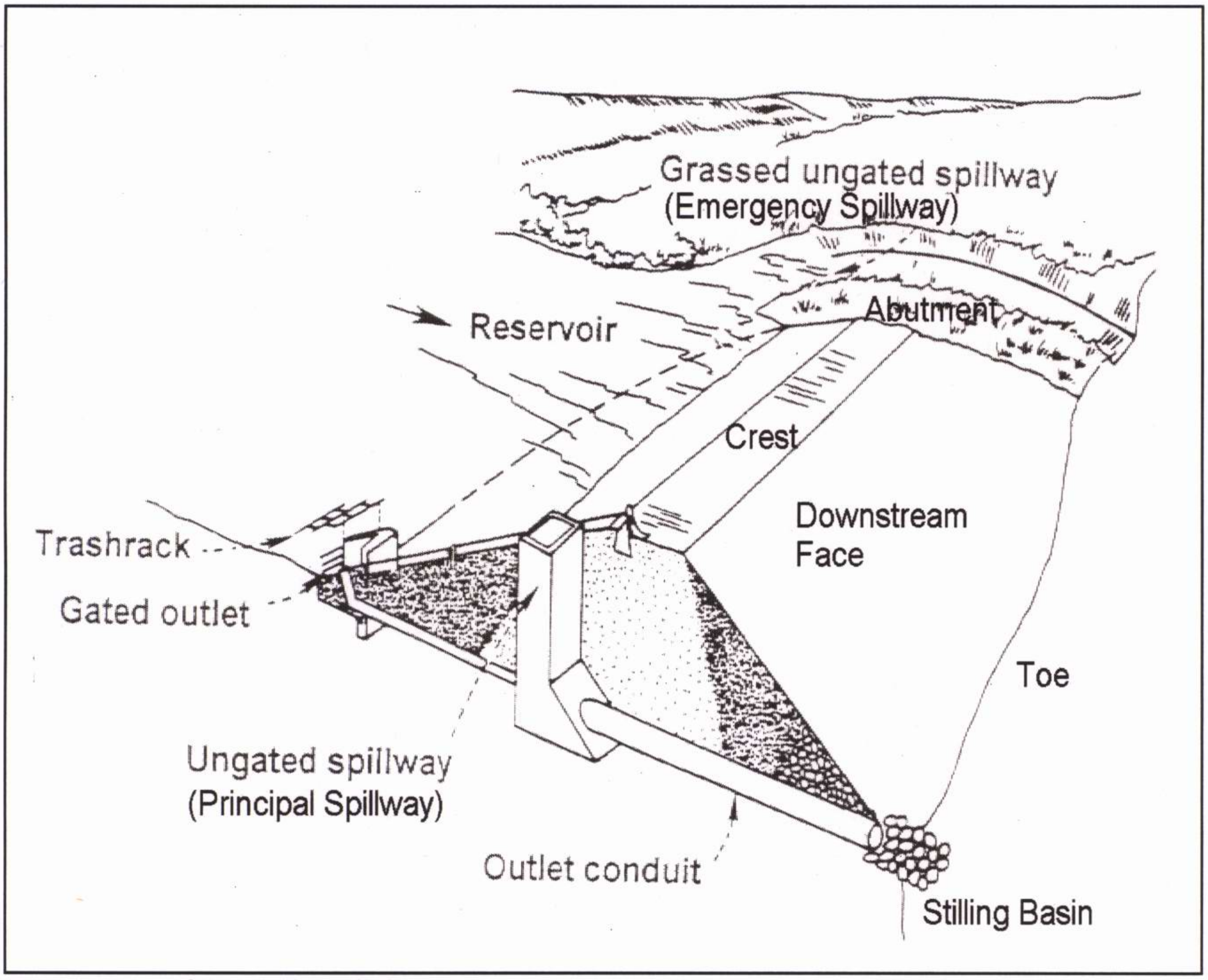
Site reclamation is the last step in building a dam. The fifth section of this guide describes what you need to do to properly reclaim your construction site.

It is obvious to most that there is liability associated with owning or even being involved in the construction of a dam. It is also obvious to most that this liability increases if there is potential loss of life or large property damage downstream. However, most folks do not know that there are ways to reduce this liability. The sixth section of this guidebook deals with **liability** issues of owning a dam and what you can do to minimize your liability.

If you run across an unfamiliar term as you read this manual, a glossary is provided in the seventh and final section.

One final note on this guidebook: As dams get larger, they become more difficult to build. As mentioned earlier, the guide is not intended to be a design manual, nor a reference for standards. If design information is desired, a good reference can be obtained from the Natural Resources Conservation Service (NRCS), titled *Conservation Practice Standard No. 378 PONDS*. The document contains design standards and is a "must read" for anyone building a dam. For convenience, No.378 PONDS is included in Appendix I. No. 378 POND is also available on the internet at www.ftw.nrcs.usda.gov/nhcp_2.html. Appendix II contains a list of additional resources that you may find useful.

The intent of this guidebook is to provide basic information regarding technical issues associated with dam construction and operation. Although examples of certain construction techniques, calculations, or material recommendations are included herein, the guidebook is not intended to be an all-encompassing design manual. The technical design of certain dam features (such as slope stability analysis, pipe sizing, or material selection, to mention a few) is beyond the scope of a basic guidebook, such as is presented here, and the evaluation or design of many elements associated with planning, construction, or operation of a dam must, under state law, be performed by a registered professional engineer with specific experience in the design of dams. Rather, the information included in this manual is intended to guide the prospective builder or owner as to the many aspects involved with design, construction, and operation of a small dam in the State of Montana.



Components of a typical small dam.

For more information, contact the Dam Safety Program, Montana Department of Natural Resources and Conservation at (406) 444-6613.

PERMITS

Dams often have impacts on people, property, and the environment that extend far beyond the property of the owner of the dam. Therefore, the construction of a dam always requires permits.

Critical Permits

- Water right, which allows you to legally store and use water.
- If the reservoir will store more than 50 acre-feet, then a classification of the downstream hazard is also needed.

Both of these permits are obtained from the Department of Natural Resources and Conservation (DNRC).

Other Permits

- If you are building a new dam on a perennially flowing stream, you must contact the county Conservation District for a "310 permit".
- Because constructing a dam often involves placing fill in a stream or wetland, you must contact the U.S. Army Corp of Engineers to see if the federal Clean Water Act applies (404 Permit).
- It is difficult to build a dam without having some impact during construction to nearby waterways. It is often necessary to have a Short-Term Exemption to the State Water Quality permit (318 Authorization), obtained from the Montana Departement of Environmental Quality (DEQ).

An excellent guide to permitting is available from DNRC or by contacting your local conservation district. See Appendix II for contact information.

Caution:

Starting construction without obtaining a water right or a hazard classification can be an expensive mistake!

- Your neighbors and other water right holders might not allow you to store water without a water right. Period. Do not underestimate the power they hold to put a stop to your project!
- Dams classified as "high hazard" (greater than 50 acre-feet with potential to cause loss of life downstream) have stringent requirements for design and construction. Failure to follow these requirements could result in hefty fines OR complete removal of your dam.....at your expense!

CHOOSING A SUITABLE DAM AND RESERVOIR SITE

Site selection is one of the most important aspects of constructing an earthen embankment and reservoir. If a poor site is chosen, there could be problems that last as long as the dam itself. Preliminary studies should be conducted to ensure that the proposed location makes sense from a geographic, geological, ecological, and economic standpoint.

Geographical Considerations

- Is it close enough to the fields which are to be irrigated? Do livestock have to walk too far to get to it? If its intended use is for recreation is it easily accessible?
- Is there adequate depth and capacity? The embankment should be located where the largest volume of water can be captured with the least amount of fill. Narrow sections of valleys, with steep side slopes and valley bottom slopes, tend to maximize storage. These types of locations minimize the amount of fill, reduce shallow areas in the reservoir that may cause excessive evaporation, and reduce the amount of space required.
- Is there adequate water available? If the reservoir is to be filled by surface water run-off, the contributing drainage area needs to be analyzed. The reservoir should be adequately sized to ensure that it will fill and that the dam will not be overtopped during runoff.
- Shape, slope, and vegetation conditions downstream of a potential dam site should be taken into consideration. The existance of healthy, soil-retaining vegetation in the downstream drainage indicates adequate water supplies. Overly steep valley walls adjacent to a site may indicate a potential for site impacts by landslides, debris flows, etc. Such impacts could damage a dam, bury the outlet, or reduce reservoir storage.

Caution:

If there is any question about water availability, an engineer should be consulted early in the process. There are techniques available to determine expected runoff. Knowing this in advance can save a lot of expense and heartache.

Caution:

The use of natural topographic features for dam and reservoir development should be approached cautiosly. A natural depression may look inviting as a ready-made reservoir basin, but the dam builder must question the depression's origins. Several "high and dry" dams can be visited today whose storage function was completely lost to sinkhole development within the reservoir basin.

Without valley constraints, your embankment may be very long, as shown in this Powell County dam.

CHOOSING A SUITABLE DAM AND RESERVOIR SITE *(continued)*

Geological Considerations

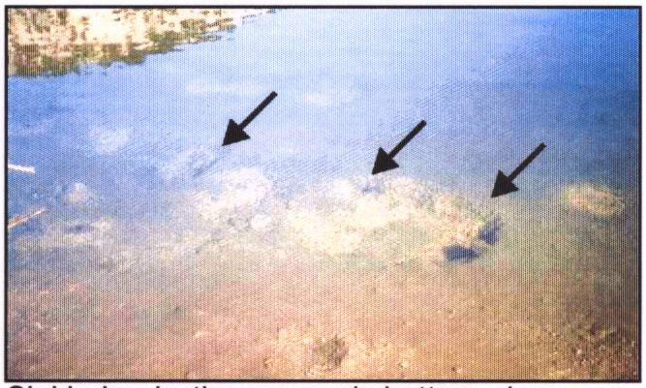
- The foundation must provide stable support for the embankment, as well as be *impervious* enough to resist seepage and excessive loss of water. Good foundation materials, which provide both stability and sufficient resistance to seepage losses, are generally *well-graded* mixtures of coarse and fine textured soils such as gravel-sand-clay mixtures.

- The reservoir area must also be able to hold water. If the reservoir bottom has sandy or gravelly soils, excessive seepage will occur, and the pond may never fill. Fractured bedrock outcrops in the reservoir also can be conduits for seepage. The ideal reservoir contains a thick continuous layer of silty or clayey material. If the proposed reservoir site is composed of sandy-gravelly soils, soil treatments and liners can be used, but they can be very expensive.

Ecological Considerations

- The reservoir and dam should not adversely impact streams, wetlands, or any other ecologically sensitive areas. **APPENDIX II** contains a list of resources to help you build a healthy, attractive, and ecologically safe pond.

This Madison County dam leaks so much through the reservoir bottom, the gates are used only two weeks per year.



Sinkholes in the reservoir bottom show one pathway water leaks from the reservior.

Caution:

Care must be taken when excavating in the reservoir area to prevent removal of low permeability soils. Low permeability soils tend to "seal" (prevent infiltration) the reservoir and prevent seepage losses. Organic soils are generally acceptable in the reservoir basin, as they generally provide a good natural liner.

Caution:

Fractures, faults, and joints in bedrock can cause unwanted seepage losses to underlying or adjacent rock formations. The concealment of such features by overlying alluvium can make their identification difficult. For this reason attention should be paid to any exposed rock outcrops in an area. Try to visualize any subsurface traces that may pose future seepage concerns, especially in areas where free-standing reservoir water or saturated soil materials may have a hydraulic connection to buried bedrock.

CHOOSING A SUITABLE DAM AND RESERVOIR SITE *(continued)*

Economical Considerations

- Construction costs escalate when embankment material must be transported to the site. Although it is important to locate the dam near potential borrow areas, it is not a good idea to borrow from the reservior area or downstream of the embankment. The location and designation of stockpile, waste sites, and borrow sites should be clearly identified and marked at the beginning of the construction project. If these areas are located too far away from the project, transportation costs will increase.
- Evaluate the area downstream of the reservoir and dam to identify anything that may be endangered if the dam were to fail. Do not overlook the possibility of a dam failure and the ecological and economic impacts that could arise from damage caused by the floodwaters. It is inadvisable to locate the dam where a failure could result in loss of life or injury to people, livestock, damage to buildings, or damage to public infrastructure.

The borrow area was located very close to this Powell County dam. This made for very cost-effective dam construction.

Downstream view from top of newly constructed Madison County dam; obvious potential liability.

Note:

If you cannot avoid downstream hazards, there are some things you can do to minimize your liability. These are discussed in greater detail in the liability section.

SUBSURFACE INVESTIGATION

Is the Dam Site Suitable?

It is critical to investigate the subsurface before designing your dam. Most subsurface investigations can be accomplished with backhoe test pits.

Test Pits

- Excavated 5 to 10 feet deep along length of embankment, outlet, and spillway.
- Don't forget potential borrow areas.
- Collect samples and take notes:
  - depth to firm material (organic & weak soils must be removed).
  - types of soils/rocks (certain soils make for a well-constructed dam).
  - are soils erodable? (erodable soils make dam susceptible to failure).
  - groundwater depth (if encountered) (high groundwater will require pumping -- increases cost).
  - boulders and large rocks - size & quantity (large rocks must be removed -- increases cost).
  - moisture (excessive moisture may make soils unusable).
  - percent of silt, clay (low permeability soils are crucial component of dam).

Caution:

If your test pits reveal permeable sands and gravels or bedrock, it is HIGHLY recommended that you hire an engineer with experience in dam design.

Note:

The embankment construction section describes simple field techniques that can be used to differentiate soils.

Note:

A sure-fire way to identify your soils is to take samples collected from your test pits to a soils laboratory. Look in theYellow Pages under "Laboratories-analytical" or "Engineers-geotechnical-soils" to find a lab that does soil analysis. Contact the lab in advance for questions on collection and transportation of the soils.

EARTHWORK: PREPARING TO BUILD DAM

Clearing and Grubbing

Most construction sites support a growth of trees, shrubs, forbs, grasses, and other vegetative growth. This vegetative growth often deposits large amounts of organic litter onto the soils surface, and the soil profile will often include large roots from trees, root wads from shrubs, and organic matter from forbs and grasses. Clearing and grubbing is simply the process of clearing the construction site of vegetation and debris. Clearing and grubbing should extend 20 to 50 feet beyond dam toe.

Vegetation removal prior to rehabilitation of Powell County dam. Note the temporary platform built to support equipment.

Stripping

After clearing and grubbing is completed, the stripping process is begun. Stripping is the removal of any unsuitable soils. Generally, this involves the excavation and removal of topsoil, which commonly contains large amounts of organic matter. Organic rich soils are undesirable in the foundation or embankment -- they are weak, tend to compress, and inhibit proper foundation drainage. Unsuitable soils should be removed 10 to 20 feet below the toe of the dam. Organic soils should be left in reservoir area.

Removal of organic soils before construction of new dam in Gallatin County. Note stream diversion pipe in background. Dewatering will be necessary before construction can proceed.

EARTHWORK: PREPARING TO BUILD DAM *(continued)*

Waste Sites

Storage of undesirable, unwanted, or excess excavated material.

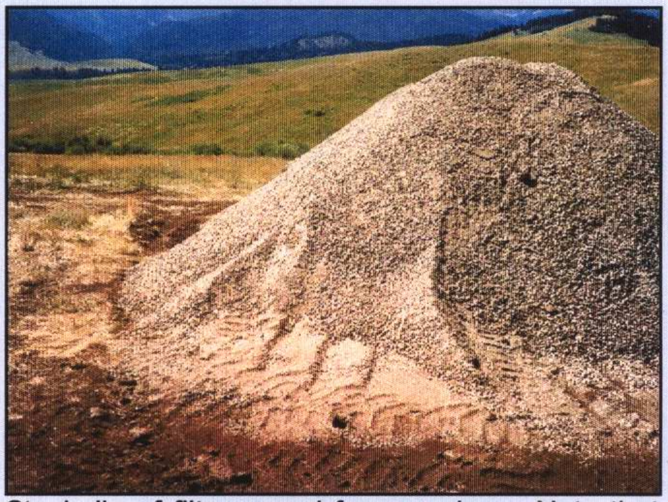
- Located close enough to allow for easy access from job site.
- Located far enough away to not interfere with construction activities.
- Shallow stable side slopes.
- Do not store waste in reservoir, toe, or abutment areas.
- Do not store waste in high groundwater areas.
- Must be reclaimed on project completion.
- Sediment and erosion controls are needed until reclamation is complete.

Note:

Topsoil and organic soil should be saved, stockpiled, and spread for reclamation of the downstream face, borrow areas, and waste areas.

Stockpiles

Storage of materials used during construction.



Stockpile of filter gravel for new dam. Note that bottom portion of stockpile is contaminated by native soil and may not be used as clean filter gravel.

- Located close to construction site for easy access.
- Located far enough away to not hamper activities.
- Located in areas where there is good drainage.
- Excessive moisture in stockpile materials increases delays and costs.
- Clean off debris to prevent contamination.
- Located so as to minimize sediment contribution to streams and wetlands.
- Stockpiles need sediment and erosion control until reclamation is complete.
- Enough room to prevent mixing.

EARTHWORK: PREPARING TO BUILD DAM *(continued)*

Borrow Areas

A good borrow area:

- Does not contain organic material.
- Drains well so that water will not collect or stand next to the borrow materials.
- Contains suitable material such as well-graded mixes of sand and clay.
- Has minimal large rocks (unless the borrow area is for rip-rap).

A less than ideal borrow site--poor draining with an apparent large variety of soils and many large rocks.

Caution:

Impervious borrow materials should be closely monitored for moisture content. Once the impervious material becomes too wet or saturated it is very difficult, costly, and time consuming to rehabilitate the material so it can be used in embankment construction.

SOILS USED IN EMBANKMENT DAMS

There are five different types of earth material used in embankment construction:

- **Clay**
- **Silt**
- **Sand**
- **Gravel**
- **Cobbles and Boulders**

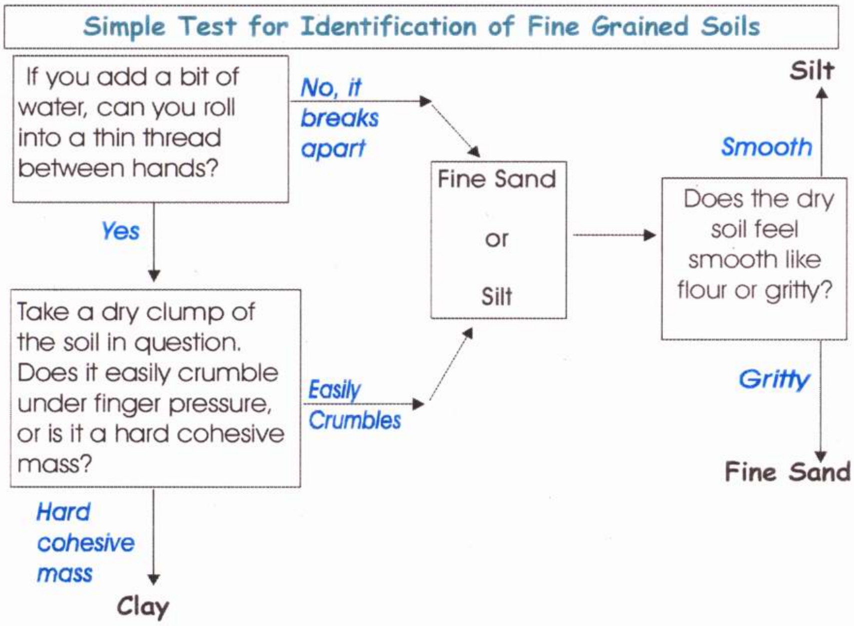
Soils are often classified into two groups: *Impermeable* and *Permeable*

- *Impermeable* materials are very slow to transmit water, and are generally used to prevent excessive seepage. Impervious soils used most commonly in embankments include clays, clayey sands or gravels, and silty clays.
- *Permeable* soils, on the other hand, easily transmit water, and are often used to control seepage. Sands and gravels are considered to be pervious. Note that the addition of only 10% clay or silt can render sand impervious and dramatically effect performance. Thus, it is very important during construction to keep pervious and impervious soils separate.

There are two common terms used to describe clay and silt-sized material: *Cohesiveness* and *plasticity*.

- *Cohesiveness* refers to a soil's ability to cling together. All clays and some silts are cohesive.
- *Plasticity* refers to the ability of a material to mold or conform. The more plastic a soil, the more moldable the soil is.
- High plasticity soils need special care: they expand and contract with addition of water and have a narrow window of moisture content where proper compaction can be achieved.
- Low plasticity, cohesive soils (clays) tend to compact well and resist piping (a form of erosion).
- Non-plastic, non-cohesive soils (most silts) can easily be piped out of an embankment, should a concentrated leak develop, and are generally weak when saturated.

Sometimes, it is difficult to tell the different fine-grained soils apart. It is important to do so, however, because clays perform very differently from silts or fine sands. There are some simple tests that can be performed in the field to help distinguish different types of soils.



Take a small pat of moist soil. Place in the palm of your hand. Tap your other hand against the hand with the soil pat.

If the top of the pat remains dull, clay is likely present.

If the top of the pat becomes shiny, there is silt or very fine sand present.

Other issues to consider when choosing material for the embankment:

Well-graded soils have a variety of grain sizes.

Soils having a wide range of grain sizes are preferable to soils with relatively uniform particle sizes. Soils with a wide range of grain sizes are said to be "well graded." Soils with a wide range of sizes are stronger, less susceptible to piping and erosion, and less compressible.

Oversized materials must be removed prior to compaction.

Cobbles and boulders in the soil may add to the cost of construction because stones with maximum dimensions greater than 75% of the thickness of the compacted layer must be removed to permit proper compaction. In general, compacted layers range from 6 to 9 inches thick. If the compacted layers in your dam are 8 inches thick, all rocks greater than 6 inches in diameter must be removed.

Rounded riprap tends to roll downslope on this Powell County dam, causing ongoing maintenance problems.

Angular soil particles have irregular shapes and boundaries. Angular soils tend to be stronger, due to the ability to interlock when compacted. This also applies when dealing with rock: angular *rip-rap* will stay in place much better than rounded stones or river rock.

SOILS TO BE AVOIDED IN EARTHEN CONSTRUCTION

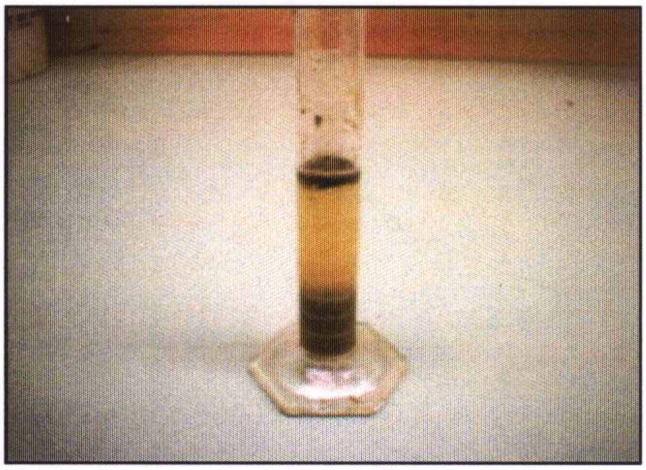
Highly plastic clays are subject to numerous problems and are generally not suitable in dams, due to their tendency to swell and shrink. A good example of a highly plastic clay is the infamous "gumbo" found in northeastern Montana. Highly plastic clays are also considered to be compressible. An embankment constructed with a plastic clay will likely see settlement and possible cracking. As discussed earlier, cracking can initiate piping!

Organic soils should also be avoided, as they are generally weak. Soils with a large amount of organic material are dark gray or black, sometimes with a slight odor. Organic soils are often found on the bottom of the proposed reservoir...another good reason to not borrow from the reservoir bottom if possible.

Caution:

Bentonite, commonly used as a "liner" material, is a good example of a highly plastic clay. As long as the bentonite is submerged, it will remain stable. However, when exposed and dried, bentonite is quick to shrink and crack. Thus, bentonite is not a suitable material when the water level in the reservoir varies seasonally.

Silt often looks like clay at first glance. However, silt is much weaker and can erode very easily in the presence of water. Look for dry clumps of soil in your sample. If the clumps crush very easily, you may have a silt on your hands. Silt is a poor construction material for dams.

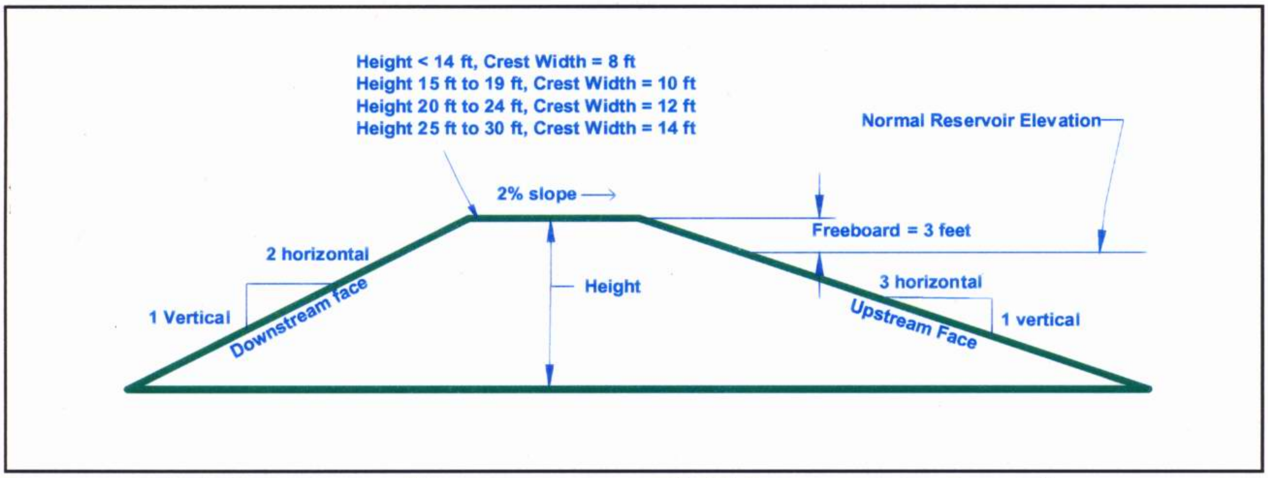


Often you cannot tell if there is organic material in your soil sample. A simple test will tell you if organics are present. Place a small amount of organic soil in a jar, shake vigorously, and then let settle. The organics will float to the top! Avoid putting organic soils in the dam embankment.

EMBANKMENT GEOMETRY

Things to consider in designing your dam:

- Is there enough distance between the reservoir and top of dam to prevent wave overtopping during a storm?
- How wide will the crest be? Can you drive a vehicle across it?
  - Increasing the top width can prevent complete dam failure should one of the slopes slide.
- How far will the slope extend upstream? Downstream?
  - Gentler slopes make for a stable dam.



Recommended slopes for small homogeneous earth fill dams on stable foundations. *NRCS Conservation practice standard POND No. 378* (Appendix I) presents some guidelines for properly sizing your dam based on dam height.

Caution:

Don't forget settlement! Most new dams will settle after construction. Settlement can reduce storage capacity and make the dam more susceptible to overtopping. It is recommended that an additional 5% of the dam height be added for settlement. Thus, if your dam is planned to be 20 feet high, then you should build it to be 20ft + (0.05 x 20ft) = 21 feet high.

This Lewis & Clark County dam settled shortly after construction. The result was deep cracks & significantly reduced freeboard.

DAM TYPE

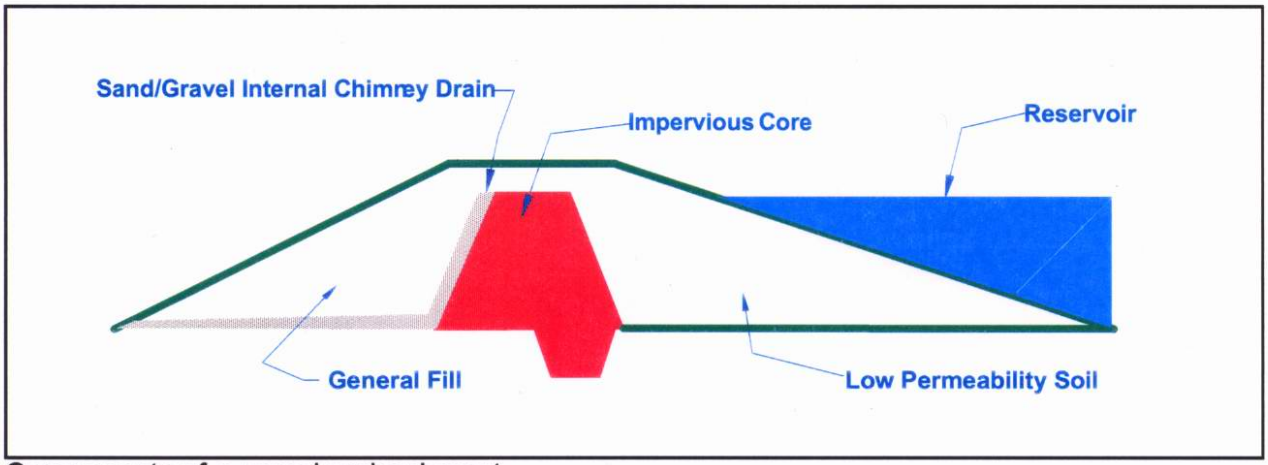
Most small earthen embankments are ***homogeneous***. A homogeneous dam lacks internal structure and has one predominant soil type. Sometimes, it is advantageous to use what is referred to as a "zoned embankment." A ***zoned*** embankment has several different soil zones within the dam, each serving a unique purpose.

Homogeneous

- Homogeneous dams are easier to construct and are therefore less expensive to build.
- Homogeneous embankments are appropriate where available fill materials are predominantly of one soil type.
- Homogeneous dams are also appropriate when the height of the dam is relatively low. Many small embankments that pose little or no downstream risk are homogeneous.

Zoned

- Embankment zoning is sometimes necessary to produce a stable structure when material availability or land is limited. Zoned embankments typically can have steeper slopes using less material.
- Zoned embankments generally control seepage much more efficiently than do homogenous embankments.
- Most of the larger embankment dams with significant downstream risk are zoned.



Components of a zoned embankment.

Caution:

Building a zoned embankment is tricky! If you decide to build a zoned embankment, you should involve a licensed engineer with dam experience.

Note:

It is possible to obtain some advantages of a zoned dam if the coarse, more pervious materials are placed at the outer slopes while the finer, impervious materials are placed in the central and upstream portions of the dam.

FOUNDATION PREPARATION

Before you begin to construct your embankment, attention must be given to the *foundation*. A properly prepared foundation is critical to the safety and long life of the embankment. First you must do an assessment of the foundation materials. What soils are present in the foundation? How thick are soil layers? How deep is bedrock? This can be easily done by examining a test pit dug with a backhoe.

Caution:

Gravels and sands make a poor embankment foundation. Gravels are highly permeable and could allow excessive seepage, which could in turn lead to dam failure or inability to hold water. Do not build your dam on gravels.

Preparation of a soil foundation:

- Scarification: loosen soils to ensure that the engineered fill bonds well with the underlying soils (usually to a depth of 6 inches).
    - During the scarification process, it is not unusual for large rocks and cobbles to be brought to the surface. Any material larger than 6 inches in diameter should be removed before the placement of fill material.
- Apply adequate moisture, so that a good bond is made. Refer to section on moisture application.
- Smooth and lessen the angle of abutment slopes.
    - It is difficult to compact fill against slopes steeper than 2:1. Poor compaction can cause a seepage path to develop.
    - Steep abutment slopes can cause cracking of the embankment fill.

Preparation of a rock foundation:

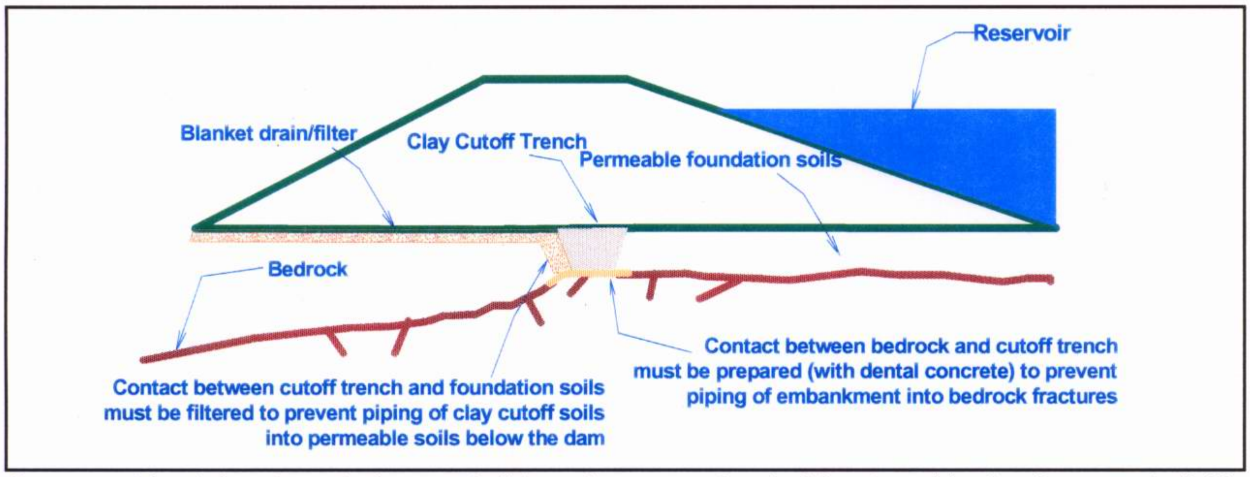
- Remove loose material.
- Seal fractures with an overlay of dental concrete.

Caution:

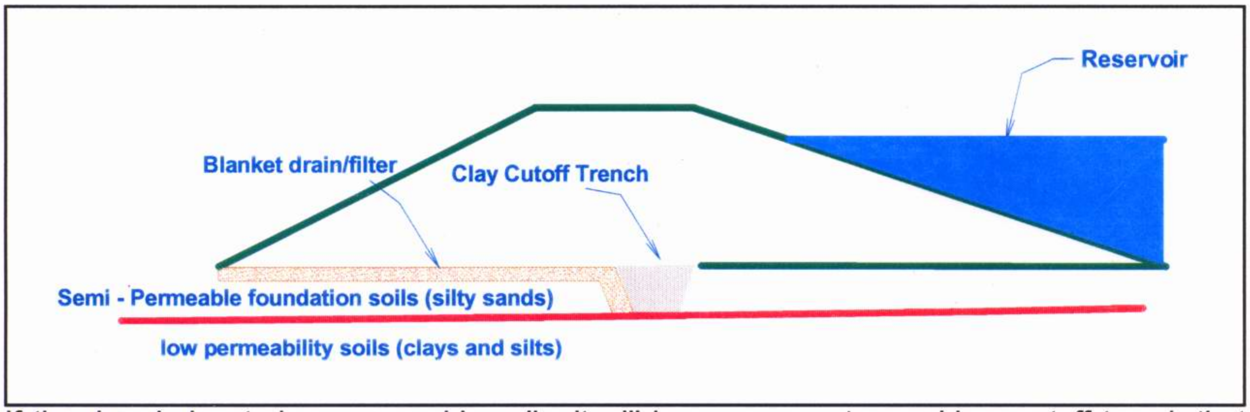
Failure to properly seal bedrock fractures has been the cause of many dam failures! Embankment material can easily be piped into open rock fractures! If you encounter rock or porous soils in the foundation, a licensed engineer with dam experience should be consulted.

FOUNDATION CUTOFF

Sometime it is necessary to provide a *cutoff trench*. The cutoff is constructed of impervious material and is generally located near the centerline of the dam. Ideally the cutoff should extend to an impervious layer in the foundation, either soil or rock. Cutoff trenches prevent excessive seepage from moving under the dam, by lengthening the seepage path.



Care must be taken to not place cutoff trenches on untreated fractured bedrock, as material in the trench could be piped into the fractures or exposed to high erosive water force. Recommendations for the installation of a cutoff trench are provided in Appendix I. Recommendations for the installation of a blanket drain/filter are located section under the "Filter Design" section.



If the dam is located on permeable soils, it will be necessary to provide a cutoff trench that extends down to a low permeability layer. The cutoff should extend the full width of the dam, including to above the normal water line in each abutment.

Caution:

If a cutoff to bedrock or to an impervious soil layer cannot be achieved, there is a good chance the reservoir will have seepage problems, perhaps even to the extent where <u>the reservoir will not hold water at all</u>! This is very common! There are several creative solutions to dealing with this situation. If you suspect this may be the case with your dam, it is highly recommended that you consult a licensed engineer.

EMBANKMENT CONSTRUCTION TECHNIQUES

Important things to remember:

- Construction should begin in cutoff trench
- Construct in nearly horizontal lifts that extend abutment to abutment.
- Borrow materials should be hauled onto *lift* (or layer) placement areas and NOT PUSHED IN PLACE!
- Once dumped, soils should be spread by dozing equipment so that their thickness is no greater than 9 inches after compaction.
- Rocks should be raked to the outer thirds of the embankment, both upstream and downstream.
- Rocks in fill should be less than 75% compacted lift thickness in size.
- Rocks should be spread out evenly and not allowed to form coarse open pockets.
- After fill has been spread and moisture properly adjusted, the soil should be compacted by either rubber tired equipment (front end loader with bucket filled) or equipment specifically designed for soil compaction.
- The embankment should be built up fairly uniformly over the entire width and length of each section as it is constructed.

Caution:

Bonding between lifts is important to prevent problems. Prior to placing the next lift (or layer), the prior lift should be scarified a maximum of 2 inches deep. Do not let lift surfaces become too dry. Frozen soil, ice, and snow should be removed.

FILL PLACEMENT - COMPACTION

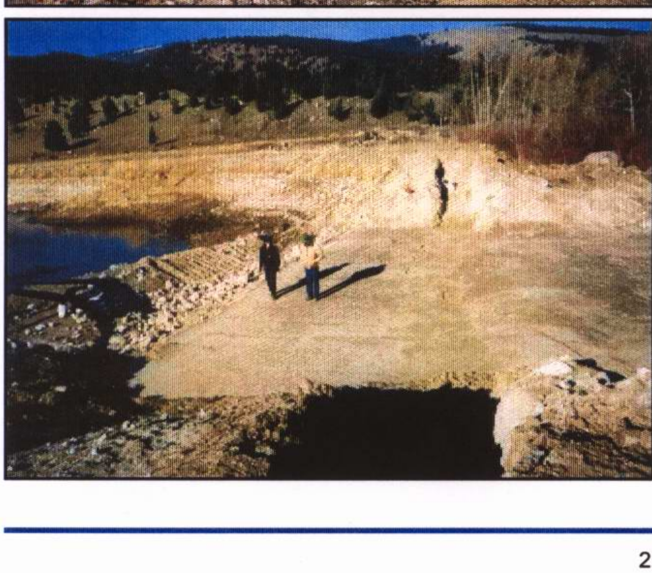
Two variables that greatly influence the embankment fill density are the compactive effort and the water content. Both are described below.

Compaction

Compaction is the process of mechanically increasing the density of the soil. By increasing the density, the strength of the soil is dramatically increased. A well-compacted soil is less likely to settle. Earth embankments are constructed in layers, commonly referred to as lifts. Dense, well-compacted lifts are paramount to having a safe dam. Compaction can be enhanced by increasing the weight of the roller on the soil, by increasing the number of passes, or by decreasing the thickness of each lift as it is added to the embankment.

The maximum diameter of stone or cobble allowed in compacted fill is generally limited to about 75 percent of the thickness of the compacted layer. Oversized rock can be efficiently removed in the borrow areas using rock separation plants (grizzly). The exception to this is impervious fill. It is difficult and expensive to process oversize rock out of impervious fill. Hand picking and rock raking generally work just as well when dealing with impervious soils. Rocks can also be rolled to the upstream face for use as rip-rap.

Impervious or semi-pervious materials are commonly compacted to a 6- to 9-inch lift thickness, with 8 to 12 passes of a sheepsfoot or pad foot roller. Clay soils require the kneading action of a sheepsfoot.



When using any roller that leaves a smooth surface after compaction, scarification of the surface of the compacted lift prior to placing the next lift will ensure a good bond between the lifts. This newly compacted surface needs scarification.

FILL PLACEMENT - COMPACTION *(continued)*

Proper compaction at the contact between the embankment, abutments, outlet pipes, and concrete structures is important. It is generally recommended that thin lifts using hand-operated tampers or hand operated vibratory plate compactors be used. The fill is commonly compacted to a maximum compacted lift thickness of 4 inches. To improve bonding of lifts, scarify the compacted surface with a roto-tiller or similar tool.

When the material that is being compacted is impervious, it should be as fine-grained as practicable. The soil must be plastic enough to penetrate all irregularities and form a well-bonded seal. The moisture content is often increased slightly to produce more plasticity in these areas. The plasticity of the contact zone of soil is sometimes increased by mixing bentonite with the available impermeable soil.

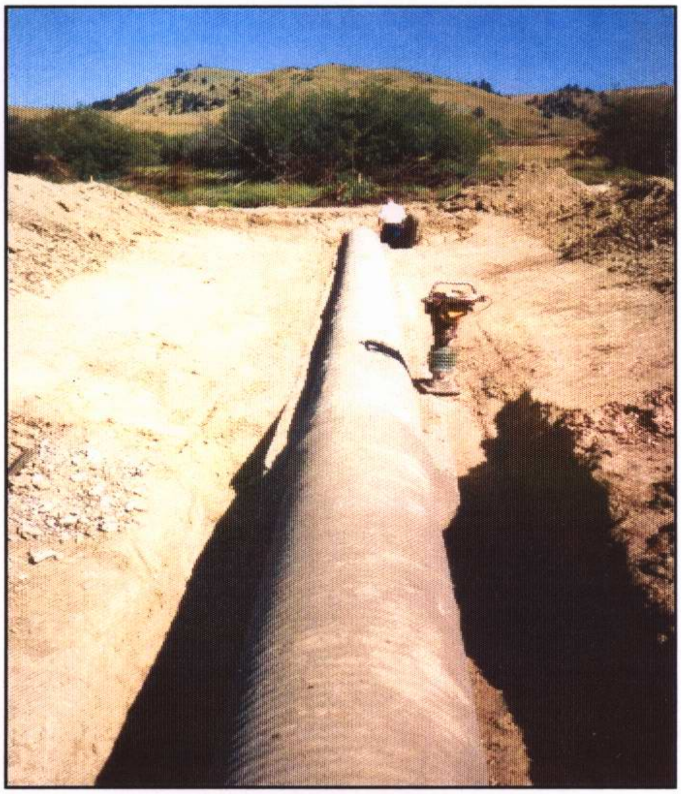
Where free-draining pervious material is placed as backfill against concrete walls and other structures such as outlet conduits, hand-operated vibratory compactors should be used. Note that vibrated plate compactors are effective only in clean non-cohesive material (sand).

Caution:

If compacting around plastic pipes, be careful that rocks are removed. Rocks can easily damage plastic pipes. Rocks with a diameter greater than 4 inches must be removed within 6 inches of the pipe.

Note:

Compaction around pipes needs to occur while the pipe is in a "trench" condition. Without a trench, there is very little lateral containment, and the soils will tend to move laterally rather than be compacted.



Compaction of low permeability material around concrete cradle for outlet pipe using hand-operated tampers.

FILL PLACEMENT - WATER CONTENT

Moisture is vital to proper compaction. Moisture acts as a lubricant within the soil, sliding the particles together. Too little moisture means inadequate compaction. Too much moisture leaves water-filled voids and weakens the soil.

The water content at maximum soil density is termed the *optimum water content.* Generally, it is recommended to have soils either at optimum water content or slightly above optimum. Soils compacted substantially drier than optimum water content may settle upon saturation. Settlements can cause embankment cracking, and even failure. Soils compacted substantially wet of optimum will be weak and non supportable.

For clays, you should be able to pick up a handful of soil and make a reasonable determination of whether or not the soil is at optimum water content by feel and appearance. A simple test is to roll out a small amount of the material on a clipboard or between the hands. Can you easily role out the soil into a thin thread without it breaking apart, or leaving wet soil behind? If so, the soil is likely very near optimum water content.

This clay soil is likely too wet. Note the wet soil left behind.

This clay soil is likely too dry. It crumbles and falls apart.

This clay soil is likely at the right water content.

FILL PLACEMENT - WATER CONTENT *(continued)*

For pervious material, the need for water content control during compaction depends on grain size. If the pervious material is gravel, no water content control is necessary. If the material is sand or contains significant proportion of sand sizes, the material should be maintained in as saturated a condition as possible during rolling. The effect of insufficient water in a pervious sand is to cause the sand to "bulk" (exhibit apparent cohesion), which will result in low strength and density when it dries out. Soils that have "bulked" might also tend to settle upon saturation.

Dry soils are treated by sprinkling water on the soil after it has been spread, but before it is compacted. The soil must be then worked to thoroughly blend the added water into the soil. This is typically accomplished by disking with a disk plow or by blading the material back and forth with a grader. If water is retained in pockets of wet soil, very poor compaction will result. The coarser and less plastic the soil, the more easily water can be added and worked uniformly into it.

Sprinkling and blending fill on Gallatin County dam under construction.

Note:

For clays, sometimes it is impossible to get a uniform moisture distribution by adding water on the fill as it is placed. Pre-wetting of borrow materials will result in more uniform moisture distribution and may be more economical. If the soil is being processed through a screening plant to remove oversize cobbles, a considerable quantity of water can be blended into the soil by sprinkling at that time.

FILL PLACEMENT - WATER CONTENT *(continued)*

Note:

The design of an embankment is strongly influenced by the natural water content of borrow materials. While natural water content can be decreased to some extent, some borrow soils are so wet they cannot be used in an embankment unless slopes are flattened. Excessively moist impervious soils may be unusable as embankment fill, and reducting moisture content would be impractical because of anticipated rainfall during construction. The cost of using drier material requiring a longer haul should be compared with the cost of using wetter materials and flatter slopes. It is generally easier to add water to dry soil than to reduce the water content of wet soil.

Are You Getting Good Compaction?

Much information can be gained by observing the action of compacting and hauling equipment on the construction surface. The action of the roller will indicate whether the water content of the material is satisfactory and if good compaction is being obtained. The action varies depending on whether the fill is pervious or impervious.

Using Your Equipment to Judge Water Content

- When compacting impervious fill, if on the first pass of a rubber-tired roller, the tires sink to a depth equal to or greater than one-half the tire width, or the soil ruts excessively after several passes, or if at any time during rolling the material is taking place ahead of the roller weaves or undulates, the water content of the material is too high.
- If the roller tracks then vary only slightly or not at all and leaves the surface hard and stiff after several passes, the soil is probably too dry.
- For most soils having proper water contents, the roller will track nicely on the first pass and the wheels will embed 3 to 4 inches. There should always be some penetration into soil at its proper water content, though the penetration will decrease as the number of passes increases.
- When using a sheepsfoot roller, another observation to be made is whether or not the feet are coming out clean; the soil is generally too wet when large amounts of material are being picked up by the feet and knocked off by the cleaning teeth. There should only be a minor amount of soil sticking if it is at its proper water content.
- At proper water content there will always be a noticeable "springing" of the embankment surface as it reacts to the passage of any heavy construction equipment.
- A sudden sinking or rising of the surface under the weight of the passing equipment is a good indication that a soft layer or pocket exists below the surface. If there is no spring at all, it is probable that several lifts of fill have been too dry.

FILL PLACEMENT - WATER CONTENT *(continued)*

Caution:

When compacting pervious sands and gravels, if the hauling and compaction equipment sinks in or causes ruts in the fill surface, this indicates that water applied during compaction is not draining through the material as it should. Watch out! This could indicate that your pervious material has been contaminated, and is not as free draining as it should be.

How To Determine If You Are Getting Adequate Compaction

Geotechnical firm using nuclear gage to test compaction on Powell County dam undergoing repair.

1. Testing using a geotechnical lab
   - For a fee, most geotechnical firms will collect samples & test for water content and compaction. Some upfront lab work must be done prior to construction to avoid delays.
2. Hand methods
   - Lightly hammering a piece of rebar into newly compacted fill can tell you a lot.
3. Keeping track of passes
   - Generally 8 to 10 passes are necessary to get adequate compaction.

Deep wheel ruts after a rainstorm signifies poor compaction in this Ravalli County dam, and many future problems.

COLD/WET WEATHER OPERATION

- Frozen soils should not be placed in the embankment. Good compaction is not obtained if the soil is frozen, even at temperatures above freezing. The important thing is to keep the construction surface "active," i.e., to continue fill placement without extensive interruptions. Freeze thaw action will eliminate the compaction in completed lifts. At the end of a shift, placing concrete blankets over the last lift may help prevent freezing. Another option is to lay down a 4- to 6-inch loose, dry lift before quitting for the day. The next morning, this loose layer of fill is removed before adding the next lift.

- The borrow source must also be protected from freezing. New lifts must be added without frozen material in them, so it is important to use an unfrozen borrow source.

- Impervious soils should never be placed on the embankment during heavy rain, as it is difficult to maintain proper water content. It is often necessary after a rainstorm to scarify and work the construction surface until it has dried to a satisfactory water content.

OUTLET FOUNDATION PREPARATION

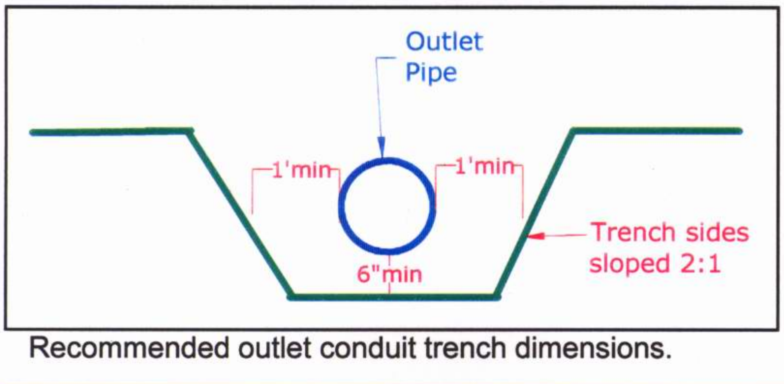
- The outlet conduit (pipe) trench should be excavated from the intake location in the reservoir basin to the downstream toe of embankment.

- Make sure bottoms and sides of trench are firm and well compacted.

- The bottom of the trench should be at least 6 inches below bottom of the pipe, and there should be a minimum of 6 inches of space between the pipe and sides of the trench.

- Trench sides should be sloped 2:1 (horizontal:vertical) to facilitate compaction (the trench walls provide lateral contianment so that all energy of compaction is directed to compaction rather than moving the material laterally).

- A hand compactor must be used to compact around outlet pipes. Most hand compactors have shoes that are at least 1 foot wide. The trench must be sized to accommodate this.



Recommended outlet conduit trench dimensions.

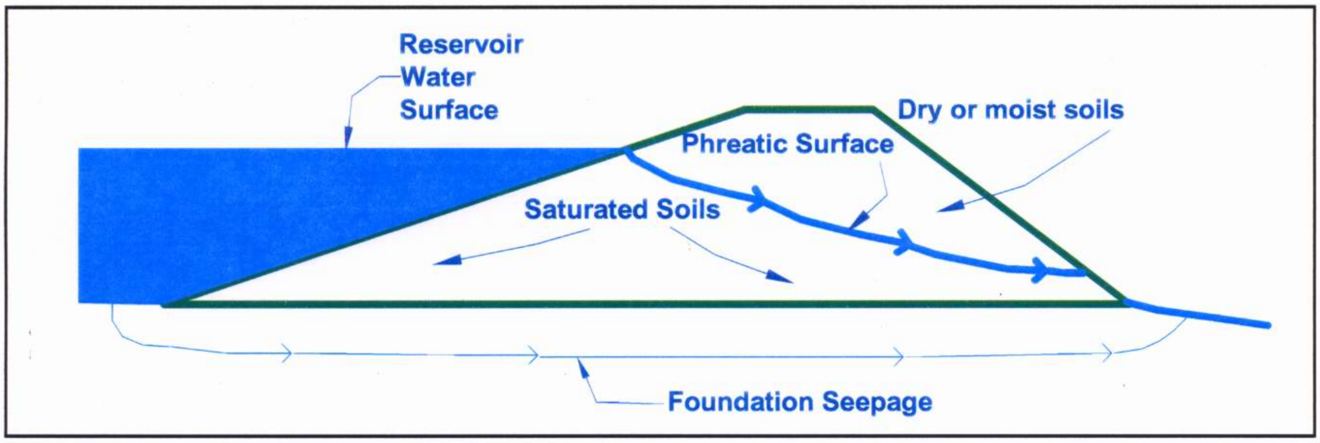
Note:

Around the sand collar (see Filter/Drain section) the trench will need to be deepened and widened to the dimensions of the collar.

SEEPAGE DEFINED

All earth dams leak to some extent. The underground leakage of water through an embankment is called seepage. Collection, conveyance, and control of seepage is a critical component of embankment construction. Thus, to build a safe, durable dam, we need to understand how water moves through a dam.

The free water surface through a dam is referred to as the *phreatic* surface. Below the phreatic surface, the embankment soils are saturated. Above the phreatic surface, the embankment soils may contain some moisture, but are not fully saturated.



Seepage water flows through both dam and foundation.

In many cases, water can move safely through the dam and foundation for years. Seepage becomes a problem when:

- The downstream embankment face becomes excessively saturated.
- Concentrated leaks develop in the embankment or foundation.

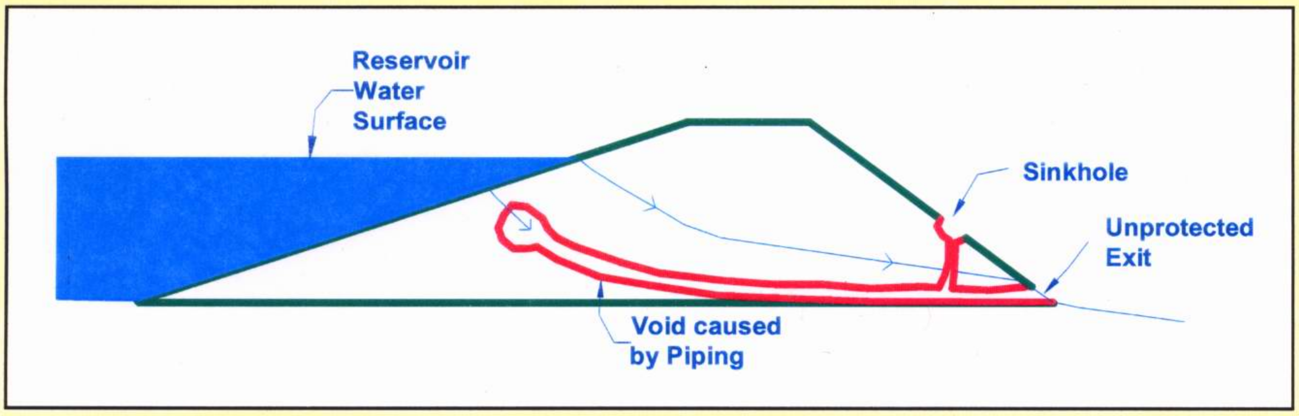
Excessive saturation of the embankment can lead to instability and slope failure. Because soil becomes more prone to failure when saturated, as the phreatic surface rises, the dam can become less stable.

Embankment instability in Wheatland County dam caused by excessive saturation.

SEEPAGE DEFINED *(continued)*

Concentrated leaks are another big concern in embankment dams. The most likely cause of a concentrated leak through a reasonably well-constructed dam is a crack. Cracks are primarily caused by differential settlement within the embankment. Differential settlement is often caused by improper compaction.

Soil particles can be transported out of the dam through a concentrated leak. This is known as *piping*. Piping proceeds very slowly and can go unnoticed for years. Finally, at some point, enough material has been moved, and the surrounding soil caves in. The surface manifestation of such as "cave in" is called a sinkhole. Sinkholes are a sign that failure of the dam could be imminent.



Sinkhole on downstream of Granite County dam, caused by slow piping of embankment material into deteriorated corrugated metal drain pipe.

SEEPAGE DEFINED *(continued)*

Piping is one of the leading causes of dam failures. The key to the prevention of piping is to install a proper filtering system that prevents the movement of soil within the embankment and foundation. A dam *filter* is similar to a coffee filter: water is allowed through, but soil particles are not. The use of filters in embankment dams is discussed later on.

Piping failure in progress at Powell County dam. This was a close call.

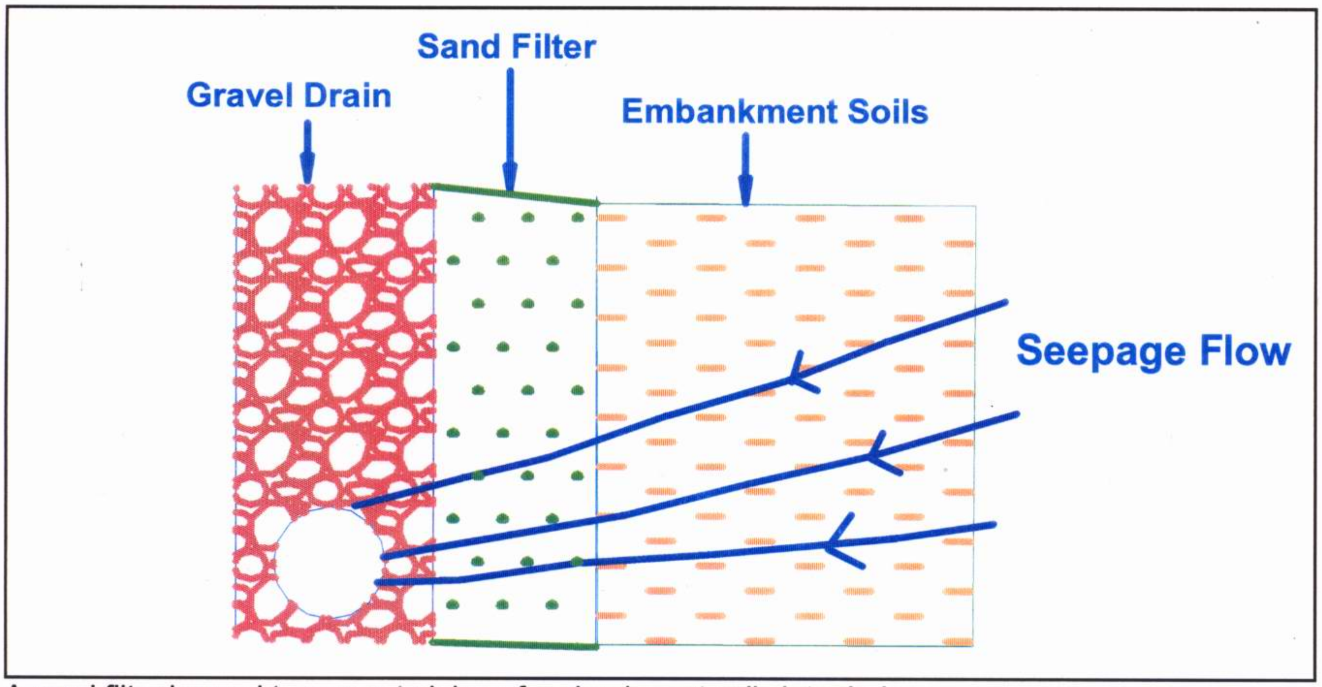
It is common to see wet soils below the toe of the dam. However, in general, you never want to see wet soils on the downstream face of the dam. This is often a sign that trouble is on the way! As discussed in the following pages, the installation of a proper drainage system is effective in keeping the embankment dry.

Although the toe area of this Meagher County dam is swampy, the embankment is bone dry. Seepage is moving primarily through the foundation.

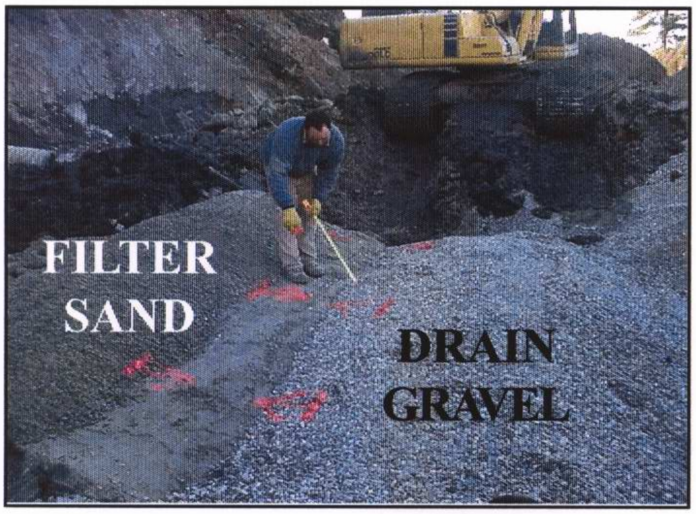
SEEPAGE CONTROL USING FILTERS AND DRAINS

Seepage can be safely controlled using filters and drains.

- *Filters* are designed to protect embankment soils from being carried away.
- *Drains* are designed to carry water away from the embankment, keeping the soils as dry as possible.
- Both filters and drains must be comprised of very pervious soils (clean sands and gravels).
- Often it is necessary to use both.



A sand filter is used to prevent piping of embankment soils into drain.

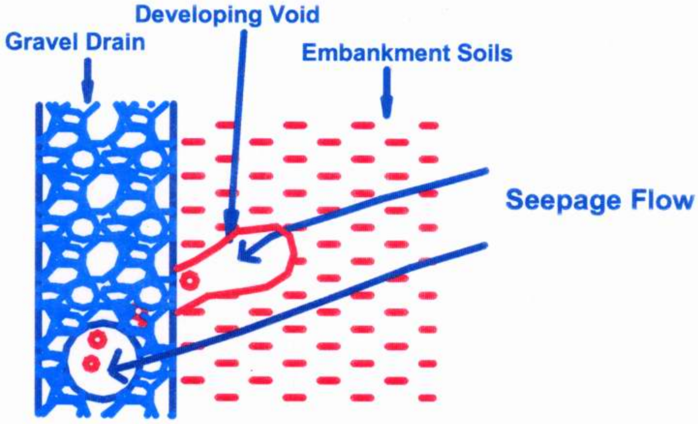


Construction of a sand filter adjacent to a gravel drain in Powell County dam.

SEEPAGE CONTROL USING FILTERS AND DRAINS *(continued)*

- It is important to make sure that the grain size of the filter material is compatible with the grain size of the embankment. As the size of the embankment material decreases, the grain size of the filter should also decrease.

- Gravel has very high permeability and works well as a drain material. However, gravel is generally too large to be placed directly next to clay soils. If a very coarse-grained soil is placed directly next to a fine-grained soil, piping could result as shown below.



Incorrect filter construction: Void developing from piping of fine-grained embankment soils into gravel drain.

In most cases, filter and drain material will have to be a processed material purchased from an aggregate supplier. Pit run borrow is usually too dirty.

The following gradation, which conforms to the 1.5-inch concrete aggregate has given satisfactory results, as **gravel drain material**:

sieve size	% finer
1-1/2	90-100
3/4	45-75
#4	30-45
#50	4-10
#100	1-3
#200	0-2

ASTM C33 fine concrete sand works well as **filter sand** for clay/silt embankments:

sieve size	% finer
3/8"	100
#4	95-100
#50	10-30
#100	2-10
#200	3-5

Caution:

The material criteria shown above can perform well in many situations. However, the drain and filter criteria shown above may not be applicable to all soil types or conditions, and the prospective dam owner/contractor should consult with a registered professional engineer for guidance in selection of drain and filter materials suited to the on-site soils and conditions.

SEEPAGE CONTROL USING FILTERS AND DRAINS *(continued)*

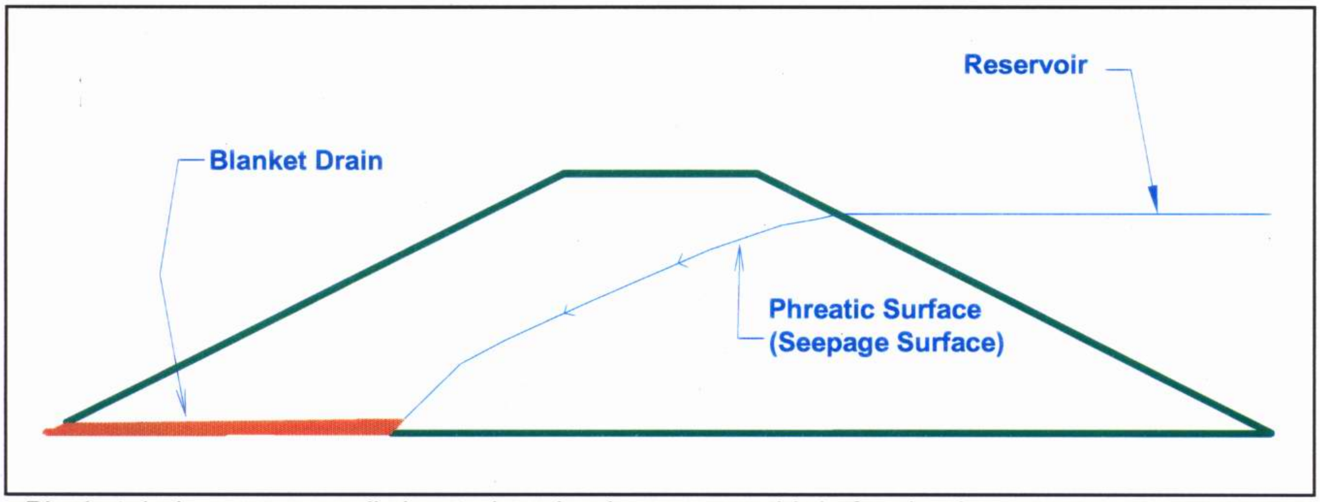
There are three main filter/drainage systems found in homogenous dams:

- Blanket Drains
- Toe Drains
- Sand Collar Filter/Drain around Outlet Pipe

Many dams have a combination of all three.

Blanket Drains

Blanket drains are used to keep the phreatic surface low and prevent saturation of soils on the downstream face of dam. Blanket drain material must be compatible with embankment soils, to prevent piping. ASTM C-33 fine aggregate concrete sand is a good blanket drain material for many soils, but not all. Drain material should be placed and compacted in 6-inch lifts with a minimum thickness of 1-foot.



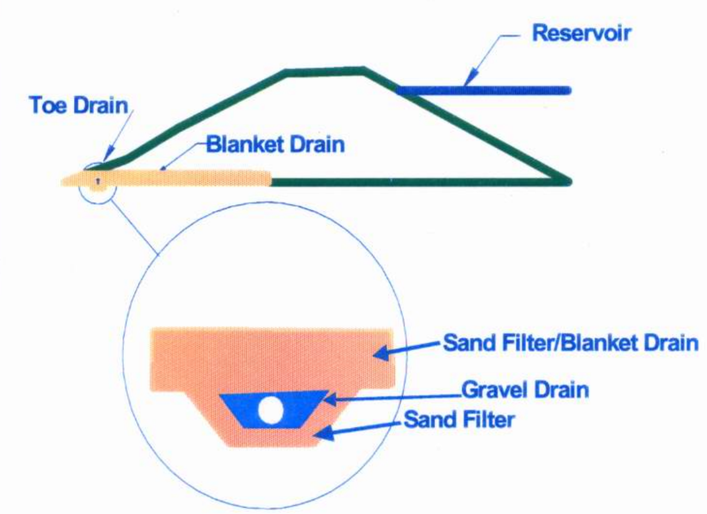
Blanket drains are generally located on the downstream third of embankment.

Construction of blanket drain at toe of Powell County dam.

SEEPAGE CONTROL USING FILTERS AND DRAINS *(continued)*

Toe Drains

Toe drains are used to collect seepage and convey it to a safe place for discharge and measurement. Typically, toe drains run parallel to the toe of the dam. Toe drains are often used in conjunction with a blanket drain. PVC pipe is commonly used as the drain pipe, but HDPE is also used. In any case, make sure perforations in the drain pipe are smaller than the surrounding material. Perforated pipe must be surrounded on all sides with a minimum of 12 inches of graveldrain material. Do not place perforated pipe in direct contact with ASTM C33 concrete sand. The sand is too small for most perforations. An engineer should be consulted on toe drain design.



Caution:
Using the wrong size material can clog the drain and cause many problems.

Typical toe drain construction.

Installation of toe drain in Powell County dam. A geotextile was used in place of a sand filter. The jury is still out on using geotextiles in dams. There is evidence that they easily clog.

SEEPAGE CONTROL USING FILTERS AND DRAINS *(continued)*

Sand Collar Filter/Drain around Outlet Pipe

Many catastrophic dam failures have occurred as the result of piping along *conduits*. The conduit or pipe represents a discontinuity in the dam and provides a preferential path for seepage. Special attention to the material surrounding the conduit is critical to the success of the project.

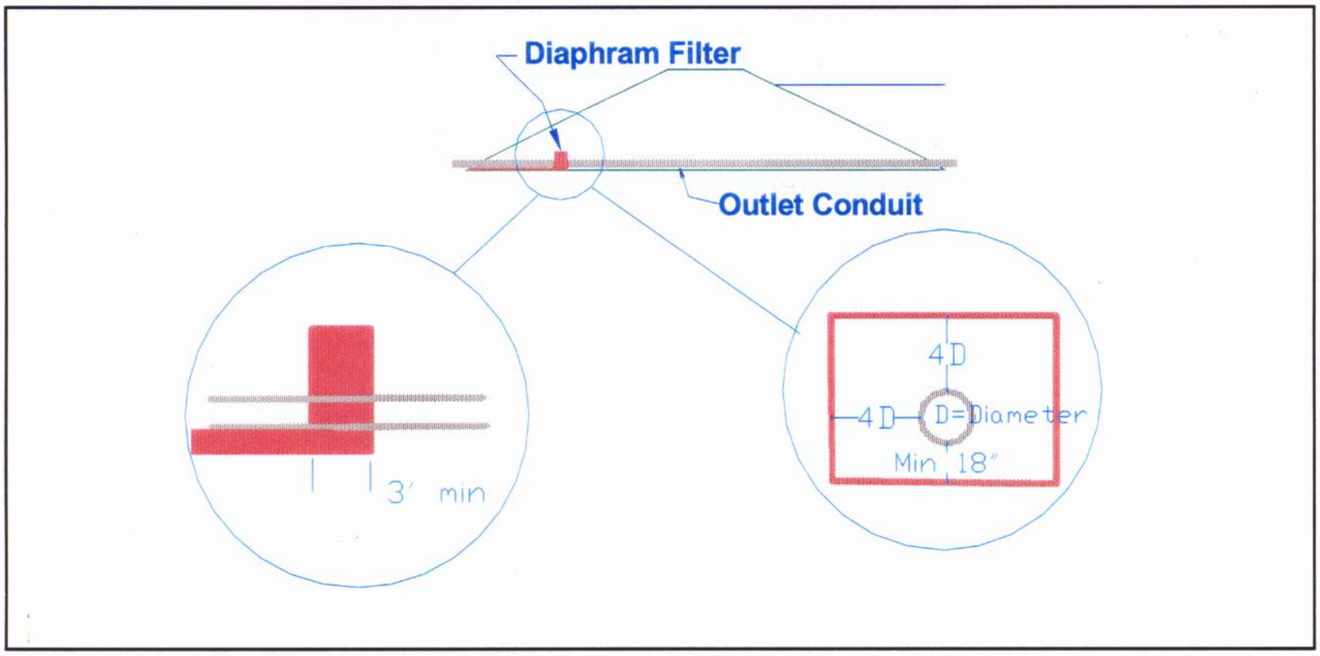
The entire contents of this Blaine County reservoir was emptied along the outside of the outlet in just a few days. Later investigation revealed that a properly installed filter diaphragm around the pipe could have prevented the failure.

Preventing Seepage around Conduit

- On the reservoir end of the conduit, the material should be impervious and compacted tightly around the pipe. The impervious material should be cohesive and plastic, so that the soil particles cannot be easily dislodged and transported as seepage flows through the dam.
- On the downstream end of the conduit, it is advisable to place a filter that ties into a drainage system. This is known as a *filter diaphragm*. The filter serves as a stop for material moving along the conduit.
  - For most small embankments, drainage sand meeting ASTM C-33 fine concrete aggregate requirements will be adequate (15% passing the #40 sieve, with no more than 10% passing #100 sieve). In some cases, a special analysis is necessary.
  - The filter diaphragm should be located midway between dam crest and downstream toe.
  - Appendix I gives recommendations for size and location of the filter diaphragm. For unusual conditions or soils, consult an engineer.

SEEPAGE CONTROL USING FILTERS AND DRAINS *(continued)*

Sand Collar Filter/Drain around Outlet Pipe *(continued)*



Filter system around outlet (diaphragm filter)

Installation of sand collar around new outlet pipe in Powell County dam. Note that bottom portion of the sand collar will need to be placed before placing the outlet pipe in trench.

Note:

Sometimes it is recommended to place perforated pipe within the sand collar material, penetrating two-thirds of the collar's length running parallel to the conduit. This pipe should be connected to a solid pipe outside the sand collar that extends to a visible location below the downstream toe of dam.

For further information on filter and drain location and design, please refer to *NRCS Conservation Practice Standard POND 378 (Appendix I)*.

SURFACE PROTECTION

Embankment surfaces must be protected from surface erosion. Upstream slope protection usually consists of rip-rap. Downstream slope protection is typically native grass cover. Always fence livestock off of dam!

Upstream Slope Protection

Protects against:

- wind
- wave erosion
- weathering
- ice damage
- potential damage from floating debris

Downstream Slope Protection

Protects against:

- surface runoff
- wind erosion
- livestock damage

Caution:

Excessive upstream face erosion can seriously threaten the dam by shortening the crest width. A dam with a narrow crest is much more susceptable to failure from overtopping or slope instability.

Erosion is slowly eating away at the crest on this Carter County dam.

Erosion has halved the crest width of this Meagher County dam.

Although usually a slow process, major slumps can occur, dramatically decreasing crest width.

SURFACE PROTECTION *(continued)*

Recommendations for placing Rip-rap:

- Watch out for *segregation*!
  - If dumping is done from trucks, dumping should proceed along horizontal rows and progress up the slope.
  - Loads should not be dumped to form vertical rows up the slope.
- Provide a bedding layer.
  - Protects the embankment material from eroding by wave action.
  - Located between the embankment and rip-rap.
  - Use proper gradation.
    - Many rip-rap failures occur because the bedding material is not large enough to resist being sucked out through the rip-rap, subsequently exposing the embankment.
  - Often, *geofabric* blankets are used for bedding. Care should be taken not to damage the blankets during rock placement.

Note:

- Particular attention and special slope protection may be necessary at the *groins* of the embankment because surface runoff from *abutments* will concentrate there.
- Surface drainage of the crest should be provided by sloping the crest gently toward the reservoir (~2% slope is good).

Placement of bedding layer on upstream face of Carbon County dam.

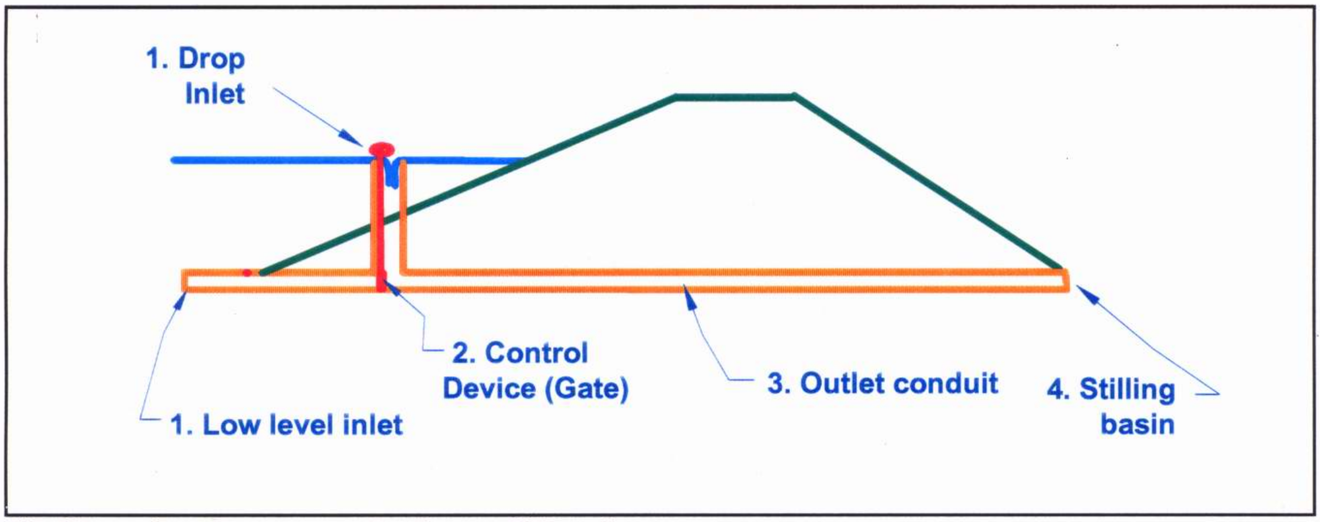
COMPONENTS OF AN OUTLET WORKS

Outlet works are installed in dams to alloww reservoir water to be released in a controlled fashion. For most reservoirs, there needs to be some means to supply irrigation water, provide for downstream water rights, and maintain streamflow for fisheries. Even for private recreation ponds, an outflow control structure is often needed to maintain the level of the pond and to prevent release of excessively warm water to downstream fisheries.

There are four primary components of an outlet works:

1. **Intake Structures or Inlets**
2. **Control Devices (gates or valves)**
3. **Pipes /Conduits**
4. **Stilling Basin**

Each component is discussed in more detail on the following pages. Brief mention will also be given to the use of siphons as an outlet alternative.



The four primary components of an outlet works.

1. INTAKE STRUCTURES

Low Level Inlet

- Used to make controlled releases.
- Storage below low level inlet is considered to be "dead storage."
- Draws water from bottom of reservoir.

Unfortunately, due to drought, we can see the low level inlet on this Wheatland County dam.

Drop Inlet

- Often called a "trickle tube."
- Allows water to enter uncontrolled when the reservoir reaches a certain level.
- Is considered to be a spillway.

Drop inlets prevent the reservoir from getting too close to top of dam.

Note:

Intake structures should always have a *trash rack*. A trash rack prevents debris from entering the outlet pipe. Debris in the outlet pipe can prevent proper gate closure. Debris can also clog the drop inlet, subsequently causing the dam to overtop. The bar spacing should not exceed 2 inches.

It is suspected that this fish screen, located inside the principal spillway of this Powell County dam, contributed to the failure of the dam. The screen clogged, allowing the reservoir to overfill.

Caution:

On some ponds it may be necessary to use a fish screen to prevent an unwanted release of pond fish. Be aware -- fish screens can easily clog and must be regularly cleaned.

2. CONTROL DEVICES

For small dams, a gate is almost always the device of choice to control flow through outlet pipes. Using a valve is generally not recommended.

A ***gate*** is a device that controls flow in a conduit without obstructing any portion of the waterway when in the fully open position.

A ***valve*** is a device used to control flow in a conduit and that permanently obstructs the waterway . Valves are constructed so that the closing member remains in the passage way for all operating conditions.

Reasons to use a gate instead of a valve:

- Access to outlet pipe for inspection: valves can prevent access to the conduit for inspection or regular maintenance, due to obstruction in the waterway.
- Gates are normally less expensive.
- Valves have potential for increased maintenance.
- Gates are easier to install.

Valves are useful when control is on the downstream side of dam, as shown in this Granite County dam. As discussed later, having the control device on the downstream side of dam is very risky.

Typical upstream slide gate used on many dams.

2. CONTROL DEVICES *(continued)*

To decide what gate to use, you must have an idea of what your operating conditions will be. For small dams under 25 feet high, light duty canal gates are commonly used.

Note:

Your choice of gate will be mostly dependent on the water depth (referred to as head) that will be in the reservoir. For example, the 24-inch canal gate shown here is reported by the manufacturer to withstand 26 feet of reservoir head. Companies that manufacture gates are usually more than willing to assist you in determining the proper gate to use

Note:

Gate delivery can be slow. Order early!

Gate Location

There are four gate configurations used on small dams:

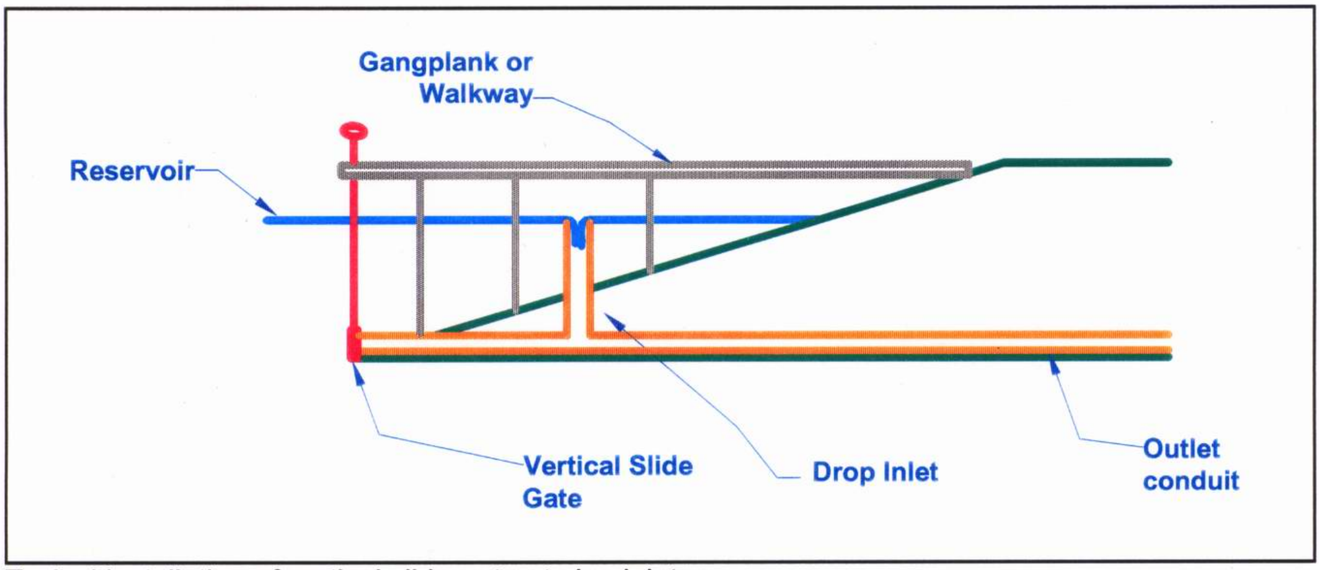
- **Gate Vertical on Pipe Inlet**
- **Gate Inclined on Upstream Face of Dam**
- **Gate Vertical Inside Drop Inlet Structure**
- **Gate in Tower on Dam Crest**

Caution:

It is almost never safe to place the gate on the downstream end of a pipe. When a gate is placed on the downstream end and is shut, the pipe is under the full pressure of the reservoir. Even tiny leaks in the pipe or joints can cause serious erosion damage to the earth fill in the dam. Large leaks can cause the dam to fail. Placing the gate on the upstream end ensures that the pipe is empty and dry when the gate is closed.

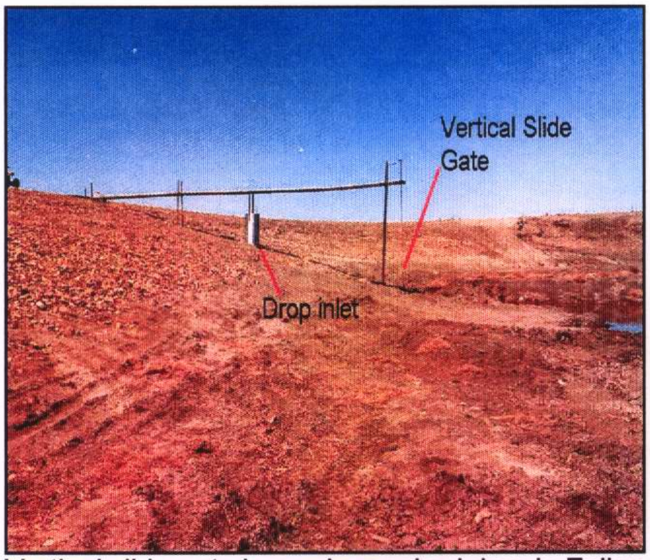
2. CONTROL DEVICES *(continued)*

Gates Vertical on Pipe Inlet



Typical installation of vertical slide gate at pipe inlet.

- Usually accessed by a walkway.
- Least expensive and easiest to install.
- Only recommended on very small reservoirs, with gentle upstream slopes. On larger ponds, the gate stem and walkway are susceptible to damage from ice. In addition, if something happens to the walkway, the gate operator cannot be accessed at full pool.

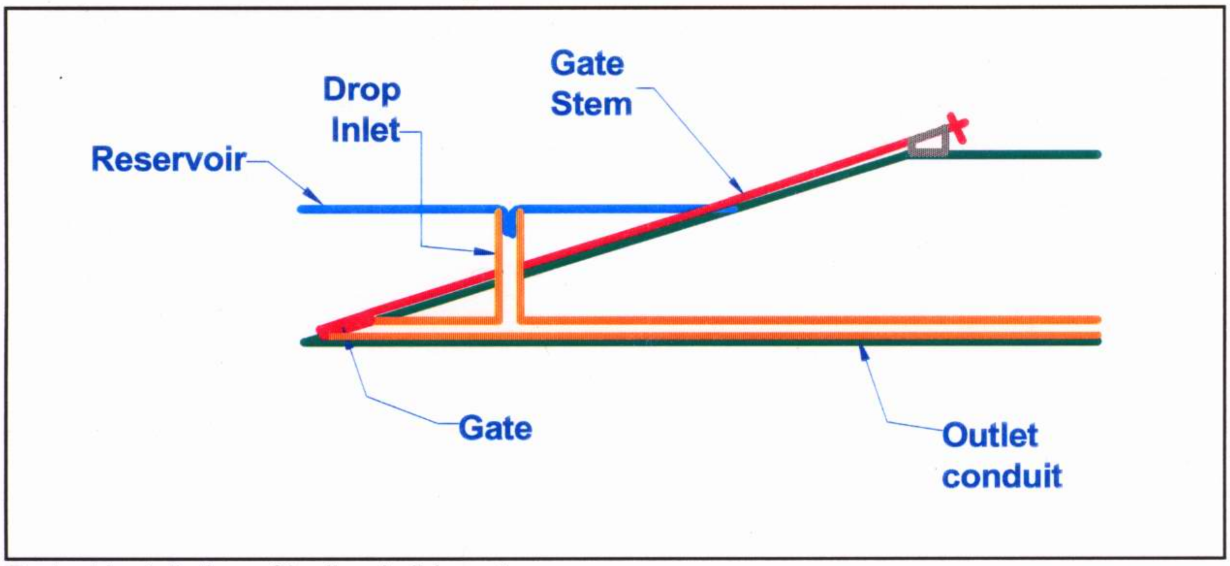


Vertical slide gate in newly repaired dam in Fallon County.

Walkway out to vertical slide gate.

2. CONTROL DEVICES *(continued)*

Gates Inclined on Upstream Face of Dam



Typical installation of inclined slide gate.

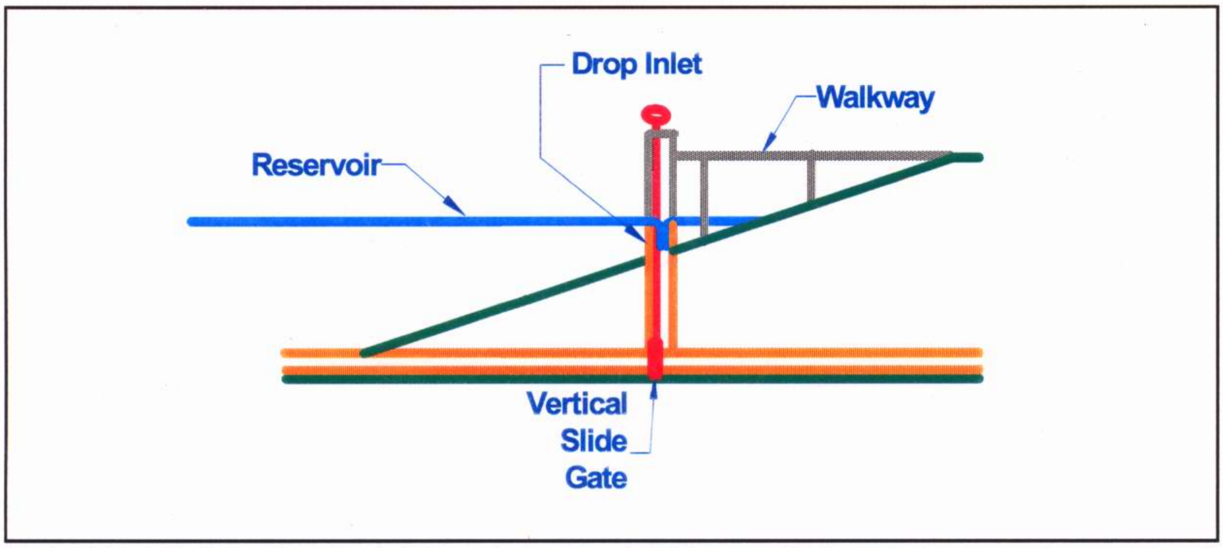
- Very common on small dams.
- Easy access to the gate operator.
- The stem must be buried and covered with rip-rap to prevent damage from ice.
- Gate is also more susceptible to blockage, so presence of trash rack is critical.
- Gate can easily be dislodged from guides.
- Maintenance costs are high -- requires draining the reservoir.

Inclined slide gates are easily damaged by debris.

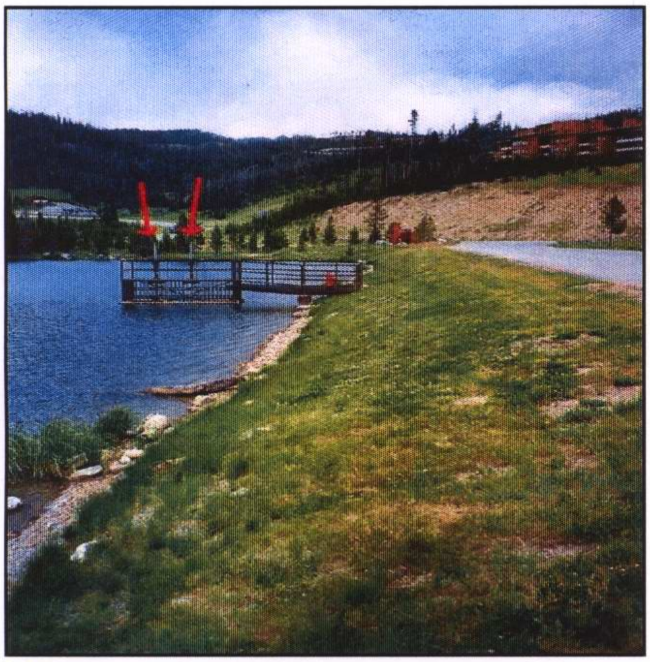
Inclined slide gate operator on small Jefferson County dam. Note the air vent (discussed later).

2. CONTROL DEVICES *(continued)*

Gate Vertical Inside Drop Inlet Structure



Typical installation of vertical slide gate in drop inlet tower. Note gate is on upstream side of drop inlet.

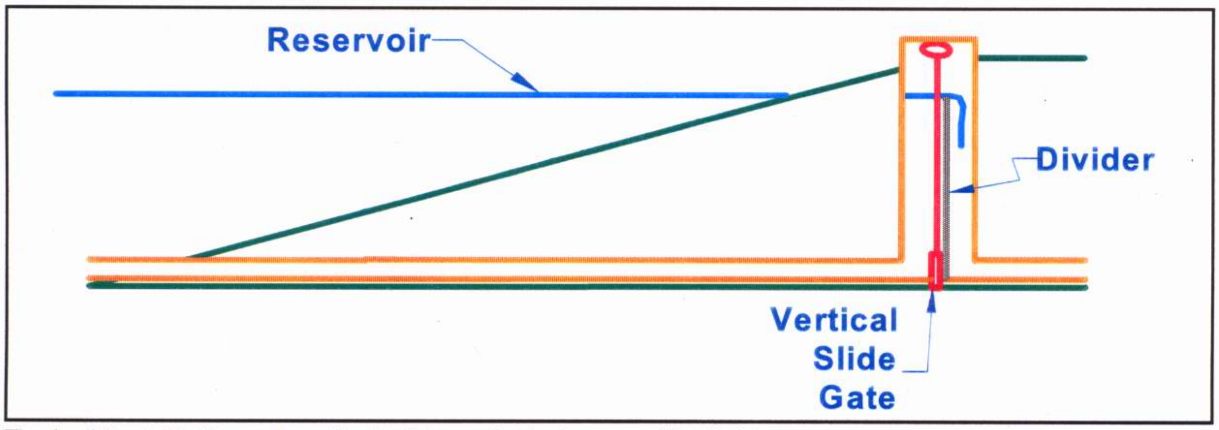


Vertical gates located in drop inlet tower of Madison County dam. The tower protects the gate stems from ice damage. Arrows point to gate operators.

- Drop inlet tower provides structural support for gate and access walkway.
- Reduces the potential for ice damage.
- Provides easy access for repair.

2. CONTROL DEVICES *(continued)*

Gate in Tower on Dam Crest



Typical installation of vertical slide gate in tower with divider

- Very reliable configuration if installed correctly.
- Provides ease of access for operation and repair.
- Is less susceptible to ice damage.
- The "divider" can have slots for stop logs to provide additional storage capacity.
- Obtaining adequate compaction of the supporting and surrounding soils is critical in order to prevent settlement.
- Tower joints must be completely water-tight as well, to prevent seepage into embankment.
- Generally more expensive to install.
- In many cases, there is no divider and the gate is simply located on the upstream end of the tower. However, without an overflow structure, the operator must be more involved in the management of water levels and the response of the reservoir to runoff events. The overflow structure provides a fail-safe, no-maintenance method for preventing an unwanted high reservoir level.

Vertical slide gate in tower.

Close up of divider wall and stop log slot. When the reservoir exceeds the elevation of the top of the divider, water flows uncontrolled into outlet. This is an excellent way to keep the reservoir from becoming too high.

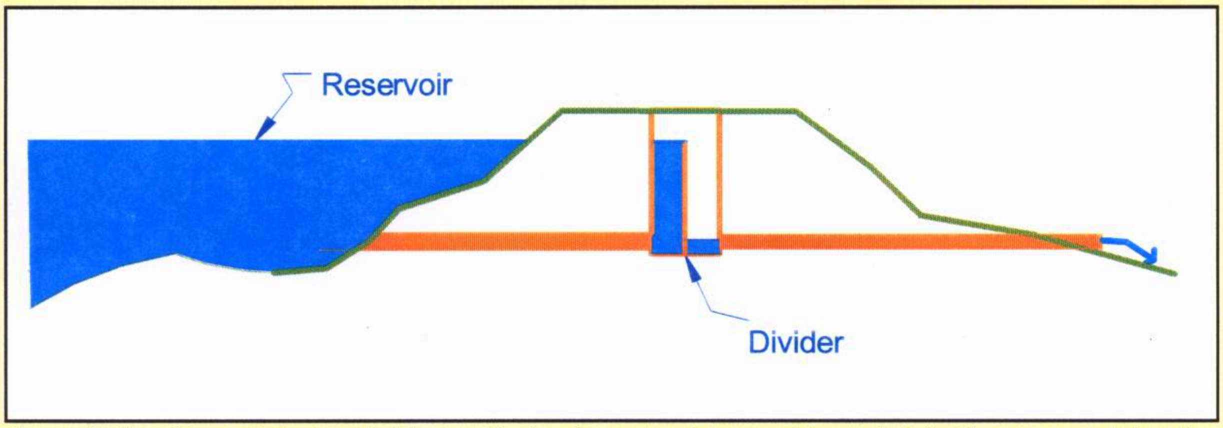
2. CONTROL DEVICES *(continued)*

Note:

Your best resource for assistance in what kind of gate system to use may be your local pipe and steel company. They stock many different kinds of gates and will help you find the right equipment for your application. They often also provide installation instructions as well.

A gate may not be necessary when:

- The pond/reservoir is maintained at a constant level for recreation year-round.
- The pond is shallow enough and dam small enough that pumps or siphons can be used to drain the pond if maintenance is necessary.
- There are no downstream hazards that could require emergency drawdown of the reservoir.



A manhole with an interior divider and *stop logs* can be used to maintain the reservoir level. No gate is necessary.

3. PIPES/CONDUITS

In general, there are four types of pipes that are used in small dams: Corrugated metal, plastic, ductile iron, and concrete. Each is briefly discussed below.

Corrugated Metal

In low water depths, simple corrugated metal pipe (CMP) with watertight bands may be sufficient.

Some of the advantages are:

- Low cost.
- Wide variety of sizes.
- Widespread local availability.

Some of the disadvantages are:

- Improper installation can lead to seepage problems.
- Subject to corrosion.
    - Outside coating is scratched as often happens during installation.
    - Depends on the quality of water that passes through the pipe. High alkaline water like that often found in eastern Montana can wreak havoc on any metal within a pipe or conduit system.
    - Internal inspection cannot detect extent of corrosion damage (corrodes from outside-in).
- Subject to abrasion from sand, silt, and rocks.
- Short design life.
- Easy to damage during installation.

A 50 year-old metal conduit pipe, recently removed from a Powell County dam.

The metal pipe in this Meagher County dam needs repair soon. Holes in the outlet pipe often initiate piping.

In some cases, corrugated metal has lasted 50 years, and while in others it has lasted less than 10. Consideration should be given to adding a protective coating.

OUTLET WORKS

3. PIPES/CONDUITS *(continued)*

Many dams have failed due to water flowing along the outside of a conduit. Adequate compaction around the pipe is key!

Erosion along the outside of this Carter County dam is becoming a problem.

The entire contents of a Petroleum County reservoir (400 acre-feet) were recently lost as reservoir water flowed along the outside of this CMP. Amazingly, the dam did not collapse.

3. PIPES/CONDUITS *(continued)*

Plastic

High-density polyethylene (HDPE) pipe is beginning to see increased use in many aspects of construction. Its use in dams is just starting, but the future looks promising.

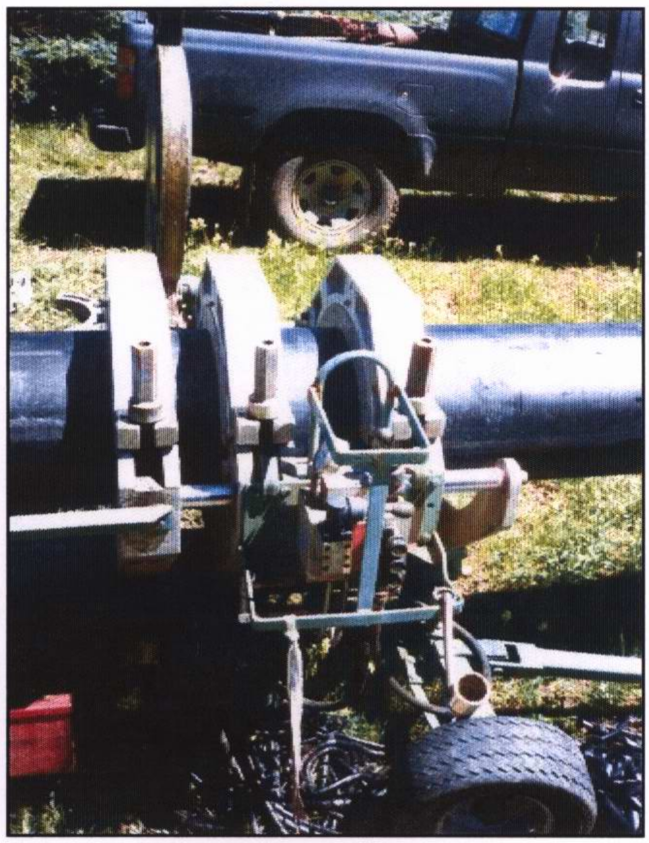
Some of the advantages are:

- Light weight.
- Nearly infallible fused joints.
- Ease with which flanges, valves and other connections can be manufactured and welded to the pipe.
- Cost effective.
- higher hydraulic efficiency (can use smaller pipe for same flow).
- Good for liners of existing pipes.

Some of the disadvantages are:

- Long term performance not proven.
- Experienced fusion welder required.
- Difficult achieving adequate compaction around pipe -- potential seepage problem. Compaction is critical for structural strength.
- Expands and contracts with daily temperature changes.

HDPE pipe was successfullly used to replace a deteriorated CMP pipe in this Powell County dam.

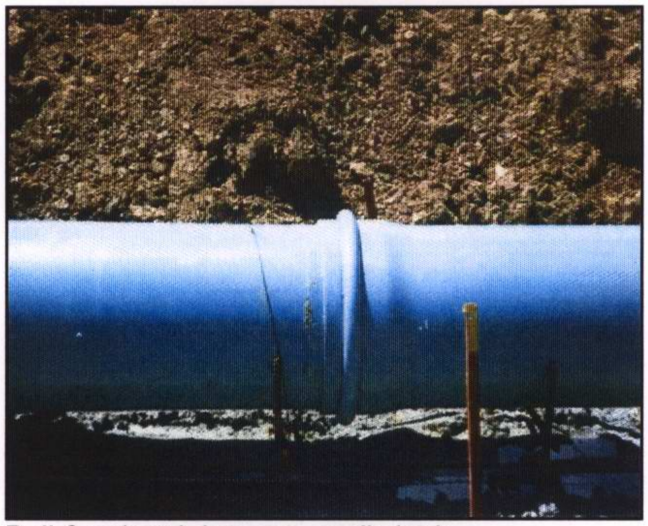


Fusion welding sections of HDPE.

3. PIPES/CONDUITS *(continued)*

Note:

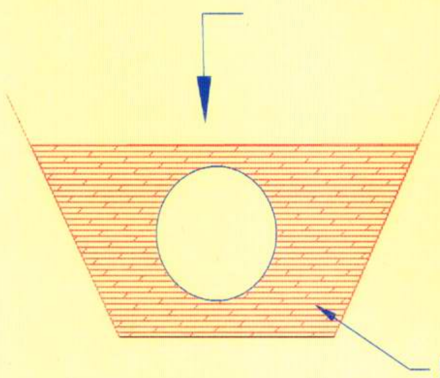
Another common plastic pipe is poly vinyl chloride (PVC). PVC pipe has been used with success on very small, low-head dams. The advantage to using PVC is its availability and cost. However, PVC is joined using a bell and spigot with a gasket. This type of joint can easily leak because of normal settlement of dam fill. Thus, it should only be used on small dams where settlement isn't a concern. It is important to pressure test before backfilling.



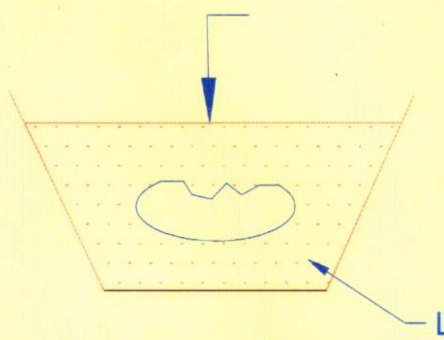
Bell & spigot joints can easily leak.

Compaction is Critical!

The strength of plastic pipe is dependent on the soil surrounding the pipe.



Plastic pipe derives its strength from the surrounding backfill. Well compacted backfill will support the pipe from high loads.



If the fill under a plastic pipe is loose, the pipe will often deflect and buckle. This is the number one cause of failure of plastic pipes, and is commonly seen.

Caution:

HDPE will expand and contract dramatically with temperature changes. If installing on a hot day, be careful you don't end up short when the pipe cools after installation.

Note:

Plastic pipe is light weight and tends to move around during compaction. Some contractors have had success bolting or welding on temporary end caps and filling the pipe with water to weight it down. This also will test joints for leaks.

3. PIPES/CONDUITS *(continued)*

Ductile Iron

Ductile iron pipes, though not typically used in small dams, is another conduit option.

Some of the advantages are:

- Local availability and installation knowledge.
- A long design life when properly installed.
- Wide variety of connections, elbows, joints, and valves that can be used.

Some of the disadvantages are:

- It requires a precise connection at all joints, flanges, and valves in order to be made water tight.
- It must be installed on a dense, compacted foundation and cannot shift or settle during construction as this can cause the joints to leak.
- Expertise required for installation can often negate the lower materials cost.
- Larger diameters are very expensive.

Note:

You may be surprised to find out that many pipe suppliers are more than willing to help you choose the right pipe for your application. They often provide installation instructions and help with finding the right connections.

3. PIPES/CONDUITS *(continued)*

Concrete

Concrete pipe is used extensively on larger dams.

Some of the advantages are:

- Available in a wide variety of sizes.
- Often available locally.
- Extremely long design life, when properly installed.
- Local expertise in installation.

Some of the disadvantages are:

- Requires careful installation procedures.
- More expensive.
- Heavy.
- Engineering design and inspection required during installation.

The concrete outlet pipe in this Jefferson County dam is almost 100 years old and is in great shape.

3. PIPES/CONDUITS *(continued)*

Choosing the Correct Pipe

The pipe you choose will need to have a few important characteristics.

- The pipe joints or connections in the pipe must be watertight up to and beyond the maximum expected depth of water, or pressure head.
    - Typically, pressure head is expressed in pounds per square inch (psi). You can get a rough estimate of the pressure in psi by multiplying the water depth to the bottom of the pipe by 0.433. So, say on a 15-foot water depth, the pipe joints would have to be water tight up to 6.5 psi.
    - Your local pipe supplier or professional engineer can help you determine the maximum pressure and what type of pipe is necessary to meet the pressure.
- The pipe must have adequate strength so that it does not collapse or distort when embankment fill is added.
    - For rigid pipes (concrete): dependent on strength of pipe.
    - For flexible pipes (plastic, CMP): dependent on strength of pipe and compaction of soil surrounding pipes.
- The pipe must have adequate capacity. A good rule of thumb is that the pipe must be big enough to draw down half of the reservoir capacity in 7 days.
- To prevent clogging and allow inspection access, the pipe should have a minimum diameter of 12 inches.
- Pond 378 in Appendix I gives a summary of pipe recommendations according to fill height.

Caution:

ALWAYS discuss your intended installation with the pipe supplier in advance. Make sure they know the following information: Height of fill above the pipe, water pressure or elevation of reservoir above the pipe, required outflow, type and size of gate you intend to use, type and size of intake structure, bedding material and required length.

Caution:

BIGGER is NOT always better! Be careful to not to use too large of a diameter for your outlet pipe! It will be difficult to maintain your desired reservoir level. Opening the gate even a small amount can result in a much larger release than you want. This is particularly important if you must operate your gate frequently as is commonly required if there are downstream water rights to be fulfilled.

3. PIPES/CONDUITS *(continued)*

Locating Your Outlet Pipe

- The pipe must be located low enough so that at least two-thirds of reservoir volume can be released.
- The pipe slope should not exceed 2 to 5% to prevent high velocities.
- Extend your pipe beyond the toe of the embankment to prevent erosion of dam.

Air Vents

All outlet works must have an air vent located just downstream of gate.

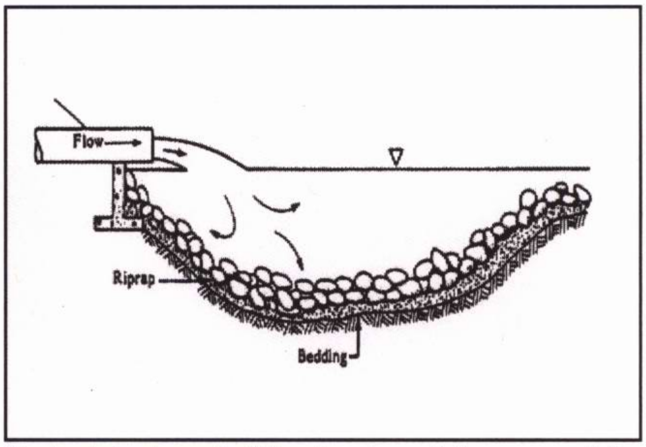
- Makes gate operator easier to activate.
- Provides *cavitation* control
- Eliminates negative pressure (vaccuum), which can collapse pipes.

Air vent on Jefferson County dam.

4. STILLING BASIN

- Located at outlet pipe exit.
- Often is rip-rap lined.
- Dissipates flows from outlet.
- Prevents scour and erosion below dam.

Simple rip-rap lined basins often perform well, as shown in this 80+ year-old Teton County dam.



Typical design of stilling basin or "plunge pool" for small dam.

This toe drain exits into stilling basin - well above high water mark - so it can easily be measured.

Note:

Drain pipes often exit into a stilling basin. It is important to design the stilling basin so that these drain pipes are not submerged when the basin is full of water.

SPILLWAY TYPES

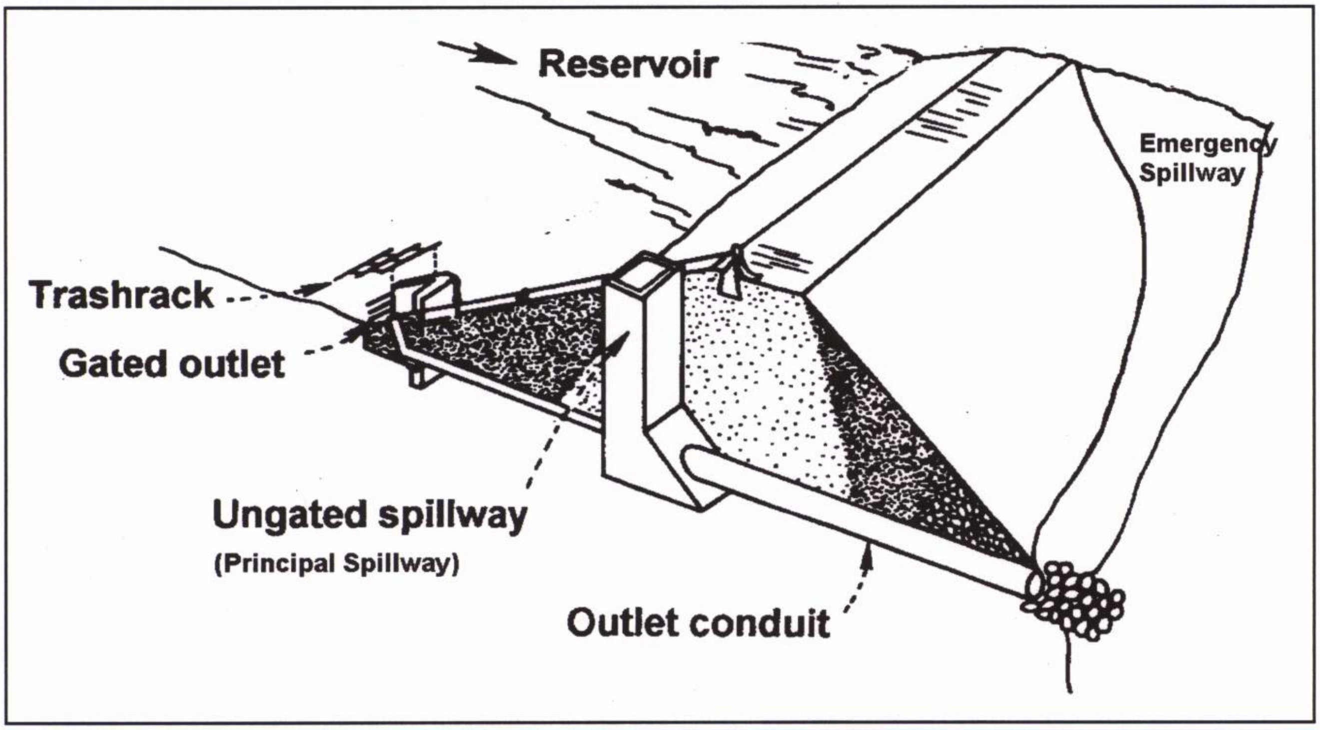
Spillways are used to by pass inflow and prevent the dam from overtopping. In Montana, overtopping is the number one cause of dam failures.

Overtopping flows nearly failed this Sheridan County dam.

There are two main types of spillways used in small dams:

- **Principal Spillways**
- **Emergency Spillways**

Usually both are required for reservoirs located on-stream. For off-stream reservoirs, sometimes only a principal spillway is needed. For off-stream reservoirs, the principal spillway is used to safeguard against operational error. For example, allowing too much inflow into the reservoir, or failing to operate the gate properly. The emergency spillway is used to safeguard against floods. More detail on each is given on the following pages.



PRINCIPAL SPILLWAYS

- Used to keep the reservoir from exceeding a certain level.
    - Do not use a gate to restrict water flow.
- Important safeguard against operational error, for off-stream reservoirs.
    - Handles the maximum amount of water that can be diverted into the reservoir.
- Designed to carry flow on a regular basis.
- Must be non-erosive.
    - Since there is a strong likelihood that the spillway will carry water almost every year, you don't want to repair erosion damage annually.
    - Most principal spillways for small dams consist of a pipe through the dam.
- The spillway is often a vertical riser tied into the outlet pipe, often called a *drop inlet* or *trickle tube.*
- If no outlet pipe is planned for the dam, the principal spillway can be an angled pipe through the dam that discharges into a channel below the dam.
- Trash racks are important to prevent clogging.

The drop inlet type principal spillway on this on-stream Madison County dam keeps the reservoir at a constant level, regardless of the inflow. Note the well designed trash rack.

The principal spillway on this off-stream Jefferson County dam is simply a large culvert that flows when reservoir exceeds a certain level. Since the reservoir is off-stream, ideally this spillway should rarely flow. Note debris and lack of trash rack.

Note:

A principal spillway is a necessity for most dams. For on-stream reservoirs, a principal spillway often handles frequent, almost yearly floods. Principal spillways on off-stream reservoirs handle operational errors, and should be designed to handle whatever flows can be diverted into the reservoir. Even the most diligent dam owner can make an operational error. After all, anyone can have a medical emergency or some other occurance where the supply canal is not shut off.

EMERGENCY SPILLWAYS

- Commonly seen as earthen channels located off the dam (to prevent erosion of dam embankment).
- Used to handle floods.
- Typically have much higher capacity then a principal spillway.
- Designed to carry flows infrequently AND often damaged when used.
  - After significant water flows, maintenance is usually required.
- Need dependent on:
  - The drainage area that contributes to the reservoir.
    - If the drainage area is large, a principal spillway pipe will not have the needed capacity to convey floods. Therefore, either an emergency spillway or additional dam height (freeboard) is needed.
  - Whether there is a principal spillway.
    - If a principal spillway is not provided, an emergency spillway is necessary.

This Granite County emergency spillway was significantly damaged during high flows

Caution:

An emergency spillway is a channel built on native ground with the bottom elevation lower than the lowest dam crest elevation. This may seem elementary, but because many dams are built without consideration that the embankment may settle, there are many cases where the water would overtop the dam before entering the spillway.

Note:

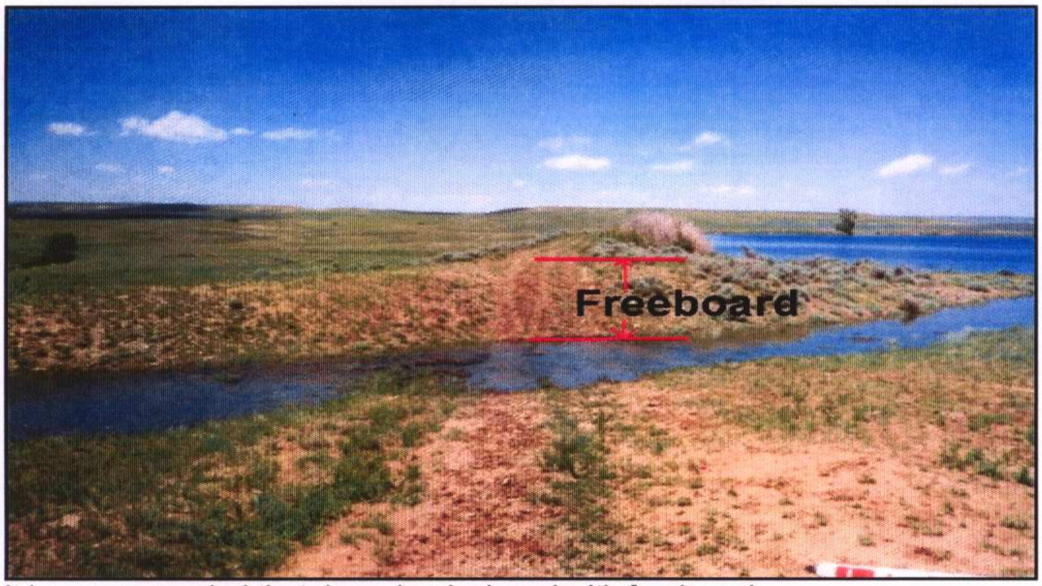
If spillway construction requires blasting of native ground, the spillway will be non-erosive and can therefore be used as both a principal and emergency spillway. In most cases however, the spillway is erosive and even if properly designed, the dam owner needs to provide regular maintenance.

EMERGENCY SPILLWAYS *(continued)*

Don't Forget Freeboard

Making the dam higher and thus increasing storage capacity is another option for controlling flood events. The distance between the crest of the emergency/ principal spillway and the top of the dam is known as *"freeboard."* If the reservoir has a large associated drainage area, the dam would need to be built to such a large height that the use of freeboard alone to contain floods becomes cost prohibitive. Freeboard is also necessary to prevent waves from overtopping the dam during a wind storm.

Minimum freeboard = 3 feet



It is recommended that dams be designed with freeboard.

Note:

The need for a principal spillway is usually obvious. However, the need for an emergency spillway or freeboard on off- stream reservoirs is often misunderstood. After all, if the dam is off-stream, why worry about flood events? Well, at a minimum, precipitation directly into the reservoir will add to lake level. Also, most off-stream reservoirs do have associated drainage areas. Keep in mind that a small flood contained within just an acre of land can easily result in flows that exceed 200 gallons per minute.

SIZING SPILLWAYS AND ACCEPTABLE RISK

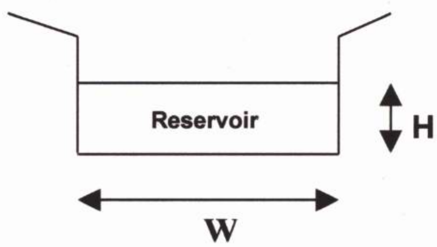
Estimating Spillway Capacity

It is highly recommended than an engineer be consulted for estimating spillway capacities.

For small dams with no downstream hazards, a simple equation can be used to give a <u>very rough</u> estimate of emergency spillway capacity:

$$\begin{array}{l} \textit{Emergency} \\ \textit{Spillway} \quad = 2.6(W)H^{1.5} \\ \textit{Capacity} \\ (\textit{in cubic feet per second}) \end{array}$$

W = Width of spillway (feet)
H = Height of water above spillway floor (feet)



Caution:

This equation is only approximate! Hiring an engineer to give an accurate value can save money in the long run.

Inflow to Reservoir in Terms of Frequency

Spillway design storms are usually presented in terms of *frequency*. The *NRCS Pond Manual* (Appendix I) gives guidelines for choosing a design storm according to dam height, reservoir capacity, and drainage area, for SMALL dams with LOW DOWNSTREAM RISK.

Caution:

It is important to note that these recommendations are for dams without potential to cause loss of life. If there is potential for downstream loss of life and/or significant property damage, higher frequency storms, such as the 500-year, should be considered.

Note:

Keep in mind that the 100-year flood is a flood that has a 1 in 100 chance each year of being exceeded. It is <u>not</u> a flood that occurs once every 100 years. For example, if a 100-year flood just occurred, there is a 5% chance that another 100-year flood, during the coming five years, could occur.

To put this all in perspective, a person should remember that they have a 1 in 3,000 chance each year of dying in an automobile accident. Do the dam owner and contractor really want to build a dam that has a 1 in 100 chance of failure when that failure could result in loss of life? If significant property damage is at stake, do the dam owner and contractor want to assume a one percent chance each year of being financially liable for a dam failure? These are all questions that the dam owner and contractor should work through before construction is started.

SIZING SPILLWAYS AND ACCEPTABLE RISK *(continued)*

Inflow to Reservoir in Terms of Quantity

There are techniques available that can be used to determine what inflow to the reservoir you would expect for a given frequency storm. The reservoir usually stores a portion of the inflow, with the remainder passing through the spillways. To be safe you could assume that the spillway must be large enough to safely pass the peak storm flow, neglecting storage in the reservoir or conduit discharge. It is recommended that an engineer be consulted to determine the reservoir inflow (design storm). Your local NRCS office may also be willing to help you determine reservoir inflow for a particular frequency storm.

Peak flows for Montana can be very roughly estimated using equations developed by the U.S. Geological Survey. Equations have been developed for eight regions in Montana.

Equations for Estimating Peak Flow

Reference: *Methods for Estimating Flood Frequency in Montana Based on Data through Water Year 1998* (USGS Water-Resources Investigations Report 03-4308).

West Region

$$Q_{25} = 8.50A^{0.835}P^{1.14}(F+1)^{-0.639}$$
$$Q_{50} = 13.2A^{0.823}P^{1.09}(F+1)^{-0.652}$$
$$Q_{100} = 18.7A^{0.812}P^{1.06}(F+1)^{-0.664}$$
$$Q_{500} = 35.4A^{0.792}P^{1.02}(F+1)^{-0.69}$$

Northwest Region

$$Q_{25} = 15.8A^{0.76}P^{0.51}$$
$$Q_{50} = 31.2A^{0.733}P^{0.445}$$
$$Q_{100} = 56.4A^{0.71}P^{0.403}$$
$$Q_{500} = 175A^{0.674}P^{0.347}$$

Southwest Region

$$Q_{25} = 109A^{0.728}(E_{6000}+1)^{-0.332}$$
$$Q_{50} = 201A^{0.704}(E_{6000}+1)^{-0.408}$$
$$Q_{100} = 351A^{0.682}(E_{6000}+1)^{-0.476}$$
$$Q_{500} = 1060A^{0.636}(E_{6000}+1)^{-0.611}$$

UpperYellowstone Central Mountain Region

$$Q_{25} = 82.6A^{0.733}(E_{6000}+1)^{-0.148}$$
$$Q_{50} = 126A^{0.716}(E_{6000}+1)^{-0.182}$$
$$Q_{100} = 181A^{0.702}(E_{6000}+1)^{-0.211}$$
$$Q_{500} = 375A^{0.674}(E_{6000}+1)^{-0.271}$$

Northwest Foothills Region

$$Q_{25} = 208A^{0.538}$$
$$Q_{50} = 318A^{0.536}$$
$$Q_{100} = 462A^{0.537}$$
$$Q_{500} = 977A^{0.544}$$

Northeast Plains Region

$$Q_{25} = 579A^{0.493}(E/1000)^{-1.21}$$
$$Q_{50} = 860^{0.477}(E/1000)^{-1.21}$$
$$Q_{100} = 1190A^{0.462}(E/1000)^{-1.20}$$
$$Q_{500} = 2130A^{0.435}(E/1000)^{-1.13}$$

(Equations for Estimating Peak Flow continued on next page)

Caution:

These equations are only estimates and may not be accurate in all situations. To avoid inaccuracies in estimating peak flow, first read and understand the reference cited above.

SIZING SPILLWAYS AND ACCEPTABLE RISK *(continued)*

Equations for Estimating Peak Flow *(continued)*

East – Central Plains Region

$$Q_{25} = 2360A^{0.47}(E/1000)^{-2.05}$$

$$Q_{50} = 3240A^{0.462}(E/1000)^{-1.96}$$

$$Q_{100} = 4120A^{0.454}(E/1000)^{-1.84}$$

$$Q_{500} = 5940A^{0.435}(E/1000)^{-1.53}$$

Southeast Plains Region

$$Q_{25} = 249A^{0.483}(F+1)^{-.264}$$

$$Q_{50} = 355A^{0.461}(F+1)^{-.236}$$

$$Q_{100} = 486A^{0.441}(F+1)^{-.212}$$

$$Q_{500} = 905A^{0.401}(F+1)^{-.166}$$

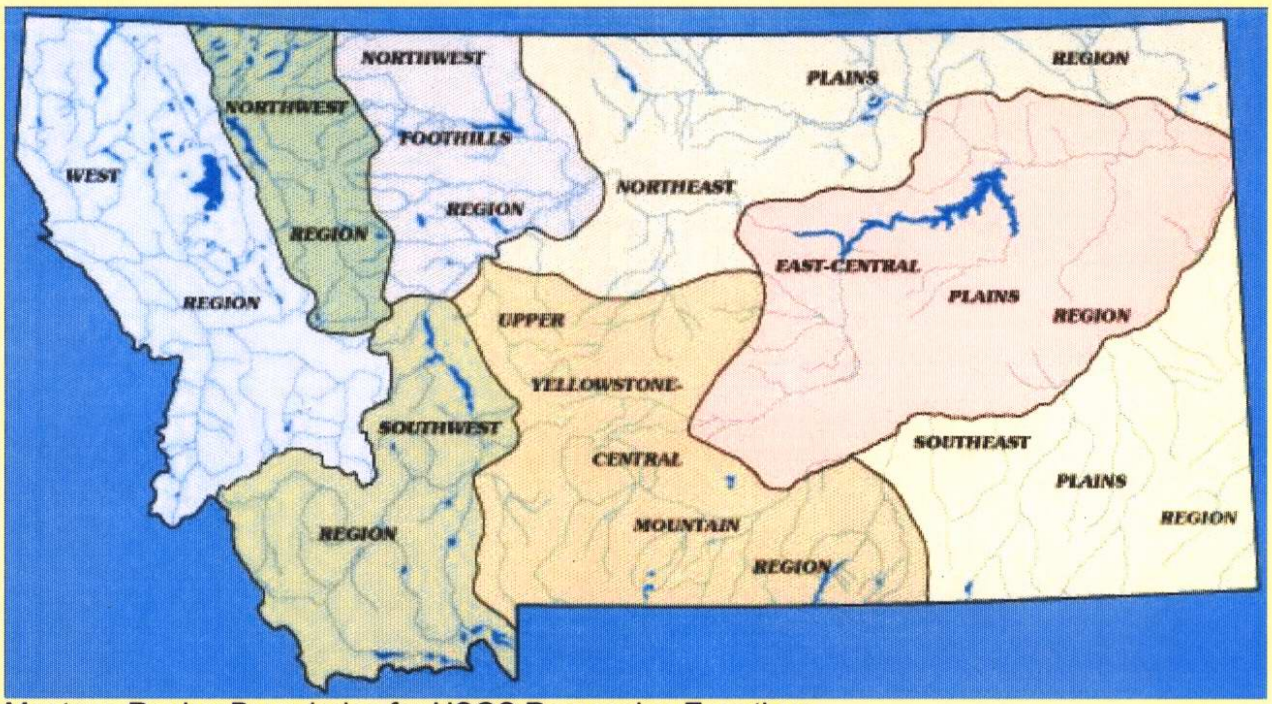
Abbreviations:

Q_t – annual peak discharge, in cubic feet per second, for recurrence interval t
A = Drainage Area in square miles
P = Mean Annual Precipitation, in inches
F = percentage of basin covered by forest
E_{6000}= Percentage of basin above 6,000 feet in elevation
E = mean basin elevation

Source: http://mt.water.usgs.gov/flood_freq/index.htm

Caution:

The importance of involving an engineer in spillway design cannot be over emphasized!



Montana Region Boundaries for USGS Regression Equations

CONSTRUCTING AN EMERGENCY SPILLWAY

Things to consider when building an emergency spillway:

- Inlet channel-
  - Must have ability to move debris (log boom).
  - Smooth transitions.
  - Level with spillway crest to avoid high velocities.

- Crest-
  - Provide layers of soil to ensure good grass growth.
  - Keep at gentle slope, to avoid high velocities.
  - Use adequate width, with an elevtion that is a minimum of 3 feet below dam crest.

- Exit Channel-
  - Gradual transition to flat slope.
  - Use natural stilling basin, if possible.

Gentle slopes on this Richland County spillway prevent damage during use, because velocities are low.

This Cascade County spillway is too steep and lacks adequate protection.

Caution:

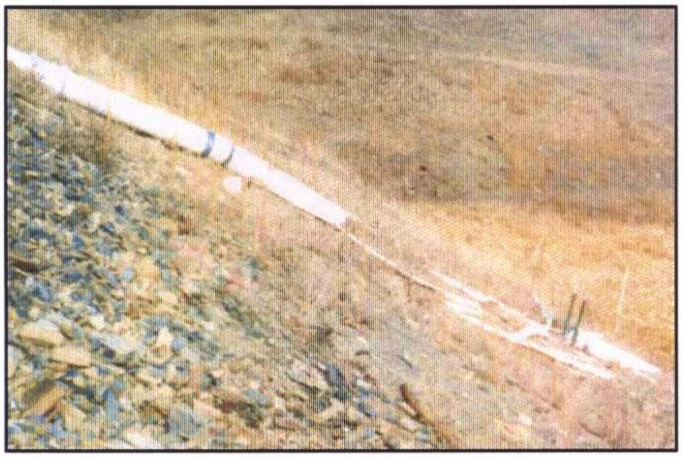
The emergency spillway should not be placed on or near the dam. Often in Montana, spillways are nearly abutted to the dam. This is a bad practice. Once significant erosion of the spillway occurs, the erosion can work itself onto the dam itself. This, of course, can lead to dam failure. The spillway should also be located so that the design flow is passed at a safe velocity to a point downstream where the dam will not be endangered

The spillway in this Cascade County dam directs water toward toe of dam - an unsafe situation.

SIPHONS

An option that is seeing more interst is the use of a siphon through the dam for emergency drawdown situations. The advantage of a siphon is that it can be buried close to the surface on the upstream, crest, and downstream portion of the dam, and can often be easily added to an existing dam. This allows for easy access should maintenance or replacement of the pipe be needed. The disadvantages are that more work is needed up front for design. Also, several elbow joints and additional pipe are required.

Siphons can be used successfully where the head is low, as shown in this Meagher County dam.



High negative pressures caused this siphon over another Meagher County dam to collapse.

Caution:

In general, for Montana, the practical limit for vertical lift by a siphon is 20 feet.

SITE RECLAMATION

After the construction phase of the project is completed, the construction site must be properly reclaimed. The two most important aspects of site reclamation are contouring and re-vegetation.

Contouring

Contouring the land to give it a natural appearance allows for the completed project to blend into the surrounding landscape and ensures good drainage and the prevention of erosion.

- All disturbed areas, such as waste and borrow areas, should be contoured to blend into the surrounding landscape in such a way that it does not promote standing water and allows for good drainage.
- Side slopes should be shallow enough to ensure slope stability under saturated conditions and should blend into the adjacent undisturbed areas.
- Temporary construction haul roads should be scarified to reduce soil compaction and contoured to blend into the surrounding areas.
- The earthen embankment should be graded and shaped so that the crest is level or slightly crowned to ensure good drainage.
- The embankment side slopes should be uniformly graded and void of any low spots or depressions.

Re-vegetation

Re-vegetation and reseeding should occur as soon as construction of the dam and reservoir is completed. The best way to protect the exposed area from erosion and weed infestations is by immediately establishing vegetation.

Areas to be re-vegetated:

- the embankment.
- the spillway.
- areas above the high water mark of the reservoir.
- stockpile, waste, and borrow areas.
- haul roads.
- staging & parking areas.

SITE RECLAMATION *(continued)*

Within one year of repair, this Powell County dam is revegating very well. The area was gently contoured and quickly seeded right after construction, which prevented erosion gullies from developing.

Do:

- Choose vegetation that can survive in the natural surroundings.
- Use native plants and grasses.
- Plant a variety of different types of trees, shrubs, forbs, and grasses.
- Irrigate recently planted areas, if possible.
- Use organic soil as top layer for reseeding.
- Pay special attention to weed control for 1 to 2 years to make sure grass has best chance of survival.

Don't:

- Plant trees and shrubs on or adjacent to the embankment and abutment areas. These types of vegetation can cause maintenance and structural problems if planted in these areas.
- Allow livestock near the area. Areas where vegetation is to be re-established should be fenced to provide protection from livestock. The fencing should be left in place for a few years.

Note:

Permanent fencing should be established around the embankment and spillway area to prevent livestock access. Not only can livestock severely degrade the vegetative cover that helps protect these areas from erosion, they often leave paths which serve as waterways for surface run off and erosion.

LIABILITY FOR DAM FAILURES

If there is downstream damage as a result of failure of your dam are you willing and able to pay the damages?

Historically, the people who have been found responsible for damages as a result of a dam failure typically include the dam owner, the landowner, the engineer, and the contractor. Dams have failed in Montana with resulting damage claims decided by the courts.

On Thursday, April 17, 1952, *Saco Independent* newspaper reported that Frenchman Dam on Frenchmen Creek, constructed the previous fall, failed during a spring storm in the Milk River drainage. The Allen Marshall home was gone, as was Winston's barn and sheds.

Big Dry and Lone Tree dams both gave way during a spring storm in March 1938. Lone Tree Dam failed first, and the partially constructed Big Dry Dam failed about three hours later, giving downstream residents time to evacuate. A number of homes near Jordan were damaged by water.

On May 27, 1948, the *Ravalli Republic* reported that Fred Burr Dam, constructed the previous fall, broke earlier that morning. No damage was reported except that the irrigators downstream of the dam would not now have the much needed supplemental water.

Wise River Patengale Dam, used for power generation, failed on June 15, 1927. Four people were killed and property was damaged in the towns of Wise River and Dewey. Considerable property damage also occurred along the Big Hole River.

The *Sidney Herald* reported on March 29, 1951, that the Vaux dams, built on Lone Tree Creek for irrigation, had washed out. There was considerable damage to homes, businesses, and county roads and bridges as a result of the water and ice chunks.

The floods of June 1964 caused the failure of Swift Dam north of Augusta, Eureka Dam near Choteau, and Two Medicine Creek Dam in Glacier National Park. On June 9, the *Great Falls Tribune* reported 8 killed and property damage in the millions of dollars..

Even recently, dams have failed. Two dams failed in the spring of 2004: one in Petroleum County (collapse of deteriorated outlet pipe), and one in Powell County (overtopping). In 2002, several stock ponds failed in the Havre area and a large reservoir failed near Jordan. In 1997, a dam near White Sulphur Springs overtopped and failed. Damage varies with the amount of development downstream and the amount of water in the reservoir.

LIABILITY FOR DAM FAILURE *(continued)*

BROWNS LAKE DAM FAILURE

The failure of Browns Lake Dam, located 11 miles west of Glen, Montana, occurred on June 20, 1984. The dam was a total loss. Browns Lake Dam was an earthen dam with a concrete headwall 50 feet long, a height of 12 feet, and capacity of 500 acre-feet. Due to overtopping and erosion, the entire dam washed out and was considered a major failure..

Two large bridges and several smaller bridges were destroyed. There also was damage to head gates, irrigation ditches, fences, and corrals belonging to Burk Ranches. Bridges, corrals, and hay and crop fields owned by the Reiber Ranch, were also destroyed.

Who Was Responsible?

Although local water users controlled the reservoir, the dam was located on state land purchased by the Montana Department of Fish, Wildlife and Parks (FWP) in the 1960s. Downstream ranches sued FWP, and FWP sued four different water users. It was decided that FWP would be responsible for $353,000 in damages. The U.S. Forest Service ended up paying $75,000 in damages for the rebuilding of roads and bridges. Finally, Beaverhead County itself shelled out nearly $50,000 for law enforcement and evacuation of campgrounds, etc. That was never brought to a claim.

Browns Lake Dam was never rebuilt after the failure in 1984. Prior to failure, it was estimated that the repair of Browns Lake Dam would cost $50,000.

This bridge, located 7 miles below Browns Lake Dam, completely washed out.

Remnants of failed Browns Lake Dam.

LIABILITY FOR DAM FAILURE *(continued)*

How Can You Protect Yourself?

The Montana Dam Safety Act provides a "liability carrot," or an incentive, to have an engineer experienced in dam construction and design oversee the construction of your dam. For instance, suppose your dam fails, and someone damaged by the failure of the dam sues you. If your dam IS NOT designed by a licensed engineer, you may be held liable, whether or not you were negligent. If your dam is designed by a licensed engineer, the damaged party must show that you or your engineer were negligent, in order to collect damages through the court. This is a more difficult test to prove.

Negligence Defined

- Negligence is the lack or failure of actions that a reasonable dam owner would perform in constructing, maintaining, and operating a dam.
- Examples of negligence:
  - allowing trees and brush grow on the dam to the extent that they hide excessive seepage.
  - allowing gophers and rodent holes to accumulate on the face of the dam until a breach is imminent.
  - failure to properly compact the fill material of the dam.
  - failure to provide for a spillway.

Note:

What can you do to demonstrate you are not a negligent dam owner?

- Have a licensed engineer design the dam and oversee construction.
- Conduct and document annual inspections (inspection forms are available from DNRC).
- Keep up with maintenance.
- If you have downstream hazards, consider developing an emergency action plan.

GLOSSARY OF TERMS

Abutment. That part of the valley side against which the dam is constructed. The left and right abutments of dams are defined with the observer viewing the dam looking in the downstream direction, unless otherwise indicated.

Acre-foot. A unit of volumetric measure that would cover one acre to a depth of one foot. It is equal to 43,560 cubic feet or 325,851 gallons. It is the volume of water delivered by a one cubic foot per second (40 miner's inches) of flow over a 12 hour period.

Appurtenant structure. Additional features of a dam such as outlets, spillways, powerplants, tunnels, etc.

Bedrock. Any sedimentary, igneous, or metamorphic material represented as a unit in geology; being a sound and solid mass, layer, or ledge of mineral matter.

Bentonite. A type of clay commonly used as a sealant.

Berm. A nearly horizontal step in the sloping profile of an embankment dam. Also a step in a rock or earth cut.

Borrow area. The area from which natural materials, such as rock, gravel, or soil, used for construction purposes is excavated.

Breach. An opening through a dam that allows the uncontrolled draining of a reservoir. A breach is generally associated with the partial or total failure of the dam.

CMP. Corrugated metal pipe.

Cofferdam. A temporary structure enclosing all or part of the construction area so that construction can proceed in the dry. A diversion cofferdam diverts a stream into a pipe, channel, tunnel, or other watercourse.

Cohesiveness. A soils ability to cling together.

Compaction. Mechanical action that increases the density by reducing the voids in a material.

Conduit. A closed channel to convey water through, around, or under a dam. Typically a pipe or fabricated tunnel.

Core. A zone of low permeability material in an embankment dam. The core is sometimes referred to as central core, inclined core, puddle clay core, rolled clay core, or impervious zone.

Crest length. The measured length of the dam along the crest or top of dam.

Crest. The highest part of the dam. It is usually the same elevation for the length of the dam and flat or slightly crowned across the dam. Often it is used for access across the dam. (See **Top of Dam**.)

Cutoff trench. A foundation excavation later to be filled with impervious material to limit seepage beneath a dam.

Dam. An artificial barrier that has the ability to impound water, wastewater, or any liquid-borne material, for the purpose of storage or control of water.

Design water level. The maximum water elevation, including the flood surcharge, which a dam is designed to withstand.

Diaphragm filter. A sand zone placed around the outlet conduit to control seepage.

GLOSSARY OF TERMS *(continued)*

Dike. An embankment to control water. Usually installed to provide freeboard in an area (a saddle) that is at or near the normal reservoir level. (see **Saddle dam**.)

Diversion channel, canal, or tunnel. A waterway used to divert water from its natural course. The term is generally applied to a temporary arrangement, e.g., to bypass water around a dam site during construction. "Channel" is normally used instead of "canal" when the waterway is short.

Drain, blanket. A layer of pervious material placed to facilitate drainage of the foundation and/or embankment.

Drain, toe. A system of pipe and/or pervious material along the downstream toe of a dam used to collect seepage from the foundation and embankment and convey it to a free outlet.

Drainage area. The area that drains to a particular point on a river or stream.

Drains. A system of perforated pipes or pervious material (sand or gravel) that is used to convey seepage water through and away from the dam embankment.

Drawdown. The difference between a water level and a lower water level in a reservoir within a particular time. Used as a verb, it is the lowering of the water surface.

Drop inlet. A vertical hollow structure (usually a pipe) set on the upstream side of a dam. The vertical structure connects to a horizontal conduit that discharges water at the downstream toe of the dam. When water reaches the level of the top of the vertical structure, it runs over the edge and is discharged downstream from the dam. This is often the primary spillway on small dams.

Erosion. The wearing away of a surface (bank, streambed, embankment, or other surface) by floods, waves, wind, or any other natural process.

Filter (filter zone). One or more layers of granular material graded (either naturally or by selection) to allow seepage through or within the layers while preventing the movement of material from adjacent zones.

Flashboards. Structural members of timber, concrete, or steel placed in channels or on the crest of a spillway to raise the reservoir water level but intended to be quickly removed, tripped, or allowed to fail in the event of a flood.

Flood. A temporary rise in water surface elevation resulting in inundation of areas not normally covered by water. Hypothetical floods may be expressed in terms of average probability of exceedance per year, such as one-percent-chance-flood (100-year flood).

Floodplain. An area adjoining a body of water or natural stream that may be covered by floodwater. Also, the downstream area that would be inundated or otherwise affected by the failure of a dam or by large flood flows. The area of the floodplain is generally delineated by a frequency (or size) of flood.

Flood routing. A process of determining progressively over time the height of a flood wave as it moves past a dam or downstream to successive points along a river or stream.

Flood storage. The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel.

Foundation. The portion of the valley floor that underlies and supports the dam structure.

Freeboard. Vertical distance between a specified elevation (typically the normal reservoir level) and the top of the dam (crest), not counting any vertical arch in the crest.

Gate. A movable water barrier for the control of water.

GLOSSARY OF TERMS *(continued)*

Geotextiles. Any fabric or textile (natural or synthetic) when used as an engineering material in conjunction with soil, foundations, or rock. Geotextiles have the following uses: drainage, filtration, separation of materials, reinforcement, moisture barriers, and erosion protection.

Groin. The area along the contact (or intersection) of the face of a dam with the abutments.

Hazard potential. The possible adverse incremental consequences that result from the release of water due to failure of the dam or mis-operation of the dam. Impacts may be for a defined area downstream of a dam from flood waters released through spillways and outlet works of the dam, or from waters released by partial or complete failure of the dam. There may also be impacts for an area upstream of the dam from effects of backwater flooding or landslides around the reservoir perimeter.

Head, static. The vertical distance between two points in a fluid.

Headwater: The water immediately upstream from a dam. The water surface elevation varies due to fluctuations in inflow and the amount of water passed through the dam.

Heel. The junction of the upstream slope of the dam with ground surface, also referred to as the *upstream toe.*

Height, above ground. The maximum height from natural ground surface to the top of a dam (crest).

Height, hydraulic. The vertical difference between the normal reservoir level and the lowest point in the original streambed.

Height, structural. The vertical distance between the lowest point of the excavated foundation to the top of the dam.

Homogeneous. Made of all the same material.

Hydrology. One of the earth sciences that deals with the natural occurrence, distribution, movement, and properties of the waters of the earth. It studies how a change in the environment (for example, vegetation in watersheds or reservoirs on streams) affects water occurrence and movement.

Impermeable. Slow to transmit water.

Inflow Design Flood (IDF). The magnitude of the flood that is used to design (size) the outlet, spillway, and freeboard of a dam.

Instrumentation. An arrangement of devices installed into or near dams that provide for measurements that can be used to evaluate the structural behavior and performance parameters of the structure. Most commonly these are observation wells to monitor groundwater levels in or near a dam, weirs or flumes to measure seepage through a dam, and fixed points (bench marks) to measure any movement of the dam.

Intake. Placed at the beginning of an outlet-works waterway, the intake establishes the ultimate drawdown level of the reservoir by the position and size of its opening(s) to the outlet works. The intake may be vertical or inclined towers, drop inlets, or submerged, box-shaped structures. Intake elevations are determined by the head needed for discharge capacity, and the desired extreme drawdown level.

Inundation map. A map showing areas that would be affected by flooding from releases from a dam's reservoir. The flooding may be from either controlled or uncontrolled releases or as a result of a dam failure. A series of maps for a dam could show the incremental areas flooded by larger flood releases. (See also **Floodplain.**)

Landslide. The unplanned descent (movement) of a mass of earth or rock down a slope.

GLOSSARY OF TERMS *(continued)*

Length of dam. The distance along the top of the dam. This also includes the spillway, powerplant, navigation lock, fish pass, etc., where these form part of the length of the dam. If detached from the dam, these structures should not be included.

Log boom. A chain of logs, drums, or pontoons secured end-to-end and floating on the surface of a reservoir to divert floating debris, trash, and logs.

Low level outlet (bottom outlet). An opening at a low level from a reservoir generally used for emptying or for scouring sediment and sometimes for irrigation releases.

Maximum reservoir level. For a reservoir with an emergency spillway, the level of the crest of the emergency spillway. For a dam without an emergency spillway, the level of the top of the dam (crest).

Minimum operating level. Some level, above the level of the intake, where head or discharge is not great enough to allow operation of the dam for its planed purpose. It is the lowest <u>useful</u> water level, even though additional water can be drawn from the reservoir through the outlet.

Normal reservoir level. For a reservoir with a fixed overflow sill the lowest crest level of that sill. For a reservoir whose outflow is controlled wholly or partly by moveable gates, siphons or other means, it is the maximum level to which water may rise under normal operating conditions.

Optimum water content. Water content in soil where highest compaction density is achieved.

Outlet. An opening through which water can be freely discharged from a reservoir to the river for a particular purpose.

Outlet works. A dam appurtenance that provides release of water (generally controlled) from a reservoir.

Peak flow. The maximum instantaneous discharge that occurs during a flood.

Permeable. A term used to refer to soils where water moves freely.

Phreatic surface. The free surface of water seeping at atmospheric pressure through soil or rock.

Piezometer. An instrument used to measure water levels or pore water pressures in embankments, foundations, abutments, soil, rock, or concrete (observation well). (See **Instrumentation**.)

Piping. The movement of soil material from the dam with water that seeps through the dam. Large voids can be created beneath the surface of the dam as water slowly moves soil through and out of the dam.

Plasticity. The ability of a soil to mold or conform.

Plunge pool. Also known as a stilling basin, is a natural or artificially created pool that dissipates the energy of free falling water, typically at the outlet of a spillway.

Reservoir. A body of water impounded by a dam.

Reservoir rim. The boundary of the reservoir includes all areas along the valley sides above and below the water surface elevation associated with the routing of the Inflow Design Flood (IDF).

Reservoir surface area. The area covered by a reservoir when filled to a specified level, typically the normal reservoir level.

GLOSSARY OF TERMS *(continued)*

Rip-rap. A layer of large random stone, precast blocks, bags of cement, or other suitable material, generally placed on the slope of an embankment or along a watercourse as protection against wave action, erosion, or scour. Rip-rap is usually placed by dumping or other mechanical methods, and in some cases is hand placed. It consists of pieces of relatively large size (often 12 inches or larger), as distinguished from a gravel blanket.

Seepage. The internal movement of water that may take place through the dam, the foundation, or the abutments.

Settlement. The vertical downward movement of a structure or its foundation.

Segregation. When soil particles separate into uniform sizes.

Slope. Inclination from the horizontal. Sometimes referred to as batter when measured from vertical.

Slope protection. The protection of a slope against wave action or erosion. (See **Rip-rap**).

Spillway. A structure over or through which flow is discharged from a reservoir. If the rate of flow is controlled by mechanical means, such as gates, it is considered a controlled spillway. If the geometry of the spillway is the only control, it is considered an uncontrolled spillway.

Spillway, emergency. Any secondary spillway that is designed to be operated infrequently, possibly in anticipation of some degree of structural damage or erosion to the spillway that would occur during normal operation.

Spillway capacity: The maximum spillway outflow that a dam can safely pass with the reservoir at its maximum reservoir level.

Spillway channel. An open channel or closed conduit conveying water from the spillway inlet downstream.

Spillway chute. A steeply sloping spillway channel that conveys discharges at high velocities.

Spillway crest. The lowest level at which water can flow over or through the spillway.

Spillway Design Flood (SDP). The magnitude of the flood that is used to design (size) the spillway for the dam. (See **Inflow Design flood (IDF)**.)

Stability. The condition of a structure or a dam when it is able to support the applied loads for a long time without having any significant deformation or movement.

Stilling basin. A basin constructed to dissipate the energy of rapidly flowing water, e.g., from a spillway or outlet, and to protect the riverbed from erosion.

Stop logs. 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 a cheaper or more easily handled means of temporary closure than an adjustable gate.

Storage. The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel. (See also **Floodplain**.) Definitions of specific types of storage in reservoirs are:

> **Active storage.** The volume of the reservoir that is available for some use such as power generation, irrigation, flood control, water supply, etc. The bottom elevation is the minimum operating level.

GLOSSARY OF TERMS *(continued)*

Dead storage. The storage that lies below the invert of the lowest outlet and that, therefore, cannot readily be withdrawn from the reservoir.

Flood surcharge. The storage volume between the top of the active storage and the design water level.

Inactive storage. The storage volume of a reservoir between the crest of the invert of the lowest outlet and the minimum operating level.

Live storage. The sum of the active and the inactive storage.

Reservoir capacity. The sum of the dead and live storage of the reservoir.

Surcharge. The volume in a reservoir between the normal reservoir level and the maximum water level. Flood surcharge cannot be retained in the reservoir but will flow out of the reservoir until the normal reservoir level is reached.

Thrust block. A massive block of concrete built to withstand a thrust or pull from a pipe, tunnel, or valve.

Top of Dam. The highest part of the dam. It is usually the same elevation for the length of the dam and flat or slightly crowned across the dam. Often it is used for access across the dam. (see **Crest**.)

Toe of dam. The junction of the downstream slope or face of a dam with the ground surface; also referred to as the *downstream toe*.

Topographic map. A detailed graphic (representation) of natural and man-made features of a region showing elevation (contour lines).

Top thickness (top width). The thickness or width of a dam at the level of the top of dam. In general, the term thickness is used for gravity and arch dams, and width is used for other dams.

Trash rack. A device located at an intake to prevent floating or submerged debris from entering the intake.

Tributary. A stream that flows into a larger stream or body of water

Upstream toe of the dam. The junction of the upstream slope of the dam with ground surface, also refered to as the *heel*.

Wave protection. Rip-rap, concrete, or other armoring on the upstream face of an embankment dam to protect against scouring or erosion due to wave action.

Zoned. A term used to refer to a dam constructed of a variety of soil types.

APPENDIX I - POND 378

NRCS, NHCP
October, 1987
NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

POND
(No.)
CODE 378

DEFINITION

A water impoundment made by constructing a dam or an embankment or by excavating a pit or dugout. In this standard, ponds constructed by the first method are referred to as embankment ponds, and those constructed by the second method are referred to as excavated ponds. Ponds constructed by both the excavation and the embankment methods are classified as embankment ponds if the depth of water impounded against the embankment at spillway elevation is 3 ft or more.

PURPOSE

To provide water for livestock, fish and wildlife, recreation, fire control, crop and orchard spraying, and other related uses, and to maintain or improve water quality.

SCOPE

This standard establishes the minimum acceptable quality for the design and construction of ponds if:

1. Failure of the dam will not result in loss of life; in damage to homes, commercial or industrial buildings, main highways, or railroads; or in interruption of the use or service of public utilities.

2. The product of the storage times the effective height of the dam is less than 3,000. Storage is the volume, in acre-feet, in the reservoir below the elevation of the crest of the emergency spillway. The effective height of the dam is the difference in elevation, in feet, between the emergency spillway crest and the lowest point in the cross section taken along the centerline of the dam. If there is no emergency spillway, the top of the dam is the upper limit.

3. The effective height of the dam is 35 ft or less, and the dam is hazard class (a).

CONDITIONS WHERE PRACTICE APPLIES

Site conditions. Site conditions shall be such that runoff from the design storm can be safely passed through (1) a natural or constructed emergency spillway, (2) a combination of a principal spillway and an emergency spillway, or (3) a principal spillway.

Drainage area. The drainage area above the pond must be protected against erosion to the extent that expected sedimentation will not shorten the planned effective life of the structure. The drainage area shall be large enough so that surface runoff and groundwater flow will maintain an adequate supply of water in the pond. The quality shall be suitable for the water's intended use.

Reservoir area. The topography and soils of the site shall permit storage of water at a depth and volume that ensure a dependable supply, considering beneficial use, sedimentation, season of use, and evaporation and seepage losses. If surface runoff is the primary source of water for a pond, the soils shall be impervious enough to prevent excessive seepage losses or shall be of a type that sealing is practicable.

Conservation practice standards are reviewed periodically, and updated if needed. To obtain the current version of this standard, contact the Natural Resource Conservation Service.

APPENDIX I - POND 378 *(continued)*

PLANNING CONSIDERATIONS

Water Quantity

1. Effects upon components of the water budget, especially effects on volumes and rates of runoff, infiltration, evaporation, transpiration, deep percolation, and ground water recharge.

2. Variability of effects caused by seasonal or climatic changes.

3. Effects on the downstream flows or aquifers that could affect other water uses or users.

4. Potential for multiple use.

5. Effects on the volume of downstream flow to prohibit undesirable environmental, social or economic effects.

Water Quality

1. Effects on erosion and the movement of sediment, pathogens, and soluble and sediment attached substances that are carried by runoff.

2. Effects on the visual quality of onsite and downstream water resources.

3. Short-term and construction-related effects of this practice on the quality of downstream water courses.

4. Effects of water level control on the temperatures of downstream water to prevent undesired effects on aquatic and wildlife communities.

5. Effects on wetlands and water-related wildlife habitats.

6. Effects of water levels on soil nutrient processes such as plant nitrogen use or denitrification.

7. Effects of soil water level control on the salinity of soils, soil water, or downstream water.

8. Potential for earth moving to uncover or redistribute toxic materials such as saline soils.

DESIGN CRITERIA FOR EMBANKMENT PONDS

Foundation cutoff. A cutoff of relatively impervious material shall be provided under the dam if necessary. The cutoff shall be located at or upstream from the centerline of the dam. It shall extend up the abutments as required and be deep enough to extend into a relatively impervious layer or provide for a stable dam when combined with seepage control. The cutoff trench shall have a bottom width adequate to accommodate the equipment used for excavation, backfill, and compaction operations. Side slopes shall not be steeper than one horizontal to one vertical.

Seepage control. Seepage control is to be included if (1) pervious layers are not intercepted by the cutoff, (2) seepage creates swamping downstream, (3) such control is needed to insure a stable embankment, or (4) special problems require drainage for a stable dam. Seepage may be controlled by (1) foundation, abutment, or embankment drains; (2) reservoir blanketing; or (3) a combination of these measures.

Earth embankment. The minimum top width for a dam is shown in table 1. If the embankment top is to be used as a public road, the minimum width shall be 16 ft for one-way traffic and 26 ft for two-way traffic. Guardrails or other safety measures shall be used where necessary and shall meet the requirements of the responsible road authority.

Table 1. Minimum top width for dams

Total height of embankment	Top width
ft	ft
10 or less	6
10-15	8
15-20	10
20-25	12
25-35	14
35 or more	15

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The combined upstream and downstream side slopes of the settled embankments shall not be less than five horizontal to one vertical, and neither slope shall be steeper than two horizontal to one vertical. All slopes must be designed to be stable, even if flatter side slopes are required.

If needed to protect the slopes of the dam, special measures, such as berms, rock riprap, sand-gravel, soil cement, or special vegetation, shall be provided (Technical Releases 56 and 69).

The minimum elevation of the top of the settled embankment shall be 1 ft above the water surface in the reservoir with the emergency spillway flowing at design depth. The minimum difference in elevation between the crest of the emergency spillway and the settled top of the dam shall be 2 ft for all dams having more than a 20-acre drainage area or more than 20 ft in effective height.

The design height of the dam shall be increased by the amount needed to insure that after settlement the height of the dam equals or exceeds the design height. This increase shall not be less than 5 percent, except where detailed soil testing and laboratory analyses show that a lesser amount is adequate.

Principal spillway. A pipe conduit, with needed appurtenances, shall be placed under or through the dam, except where rock, concrete, or other types of mechanical spillways are used, or where the rate and duration of flow can be safely handled by a vegetated or earth spillway.

The crest elevation shall be no less than 0.5 ft below the crest of the emergency spillway for dams having a drainage area of 20 acres or less, and no less than 1 ft for those having a drainage area of more than 20 acres.

When design discharge of the principal spillway is considered in calculating peak outflow through the emergency spillway, the crest elevation of the inlet shall be such that the full flow will be generated in the conduit before there is discharge through the emergency spillway. The inlets and outlets shall be designed to function satisfactorily for the full range of flow and hydraulic head anticipated.

The capacity of the pipe conduit shall be adequate to discharge long-duration, continuous, or frequent flows without flow through the emergency spillways. The diameter of the pipe shall not be less than 4 in. If the pipe conduit diameter is 10 in or greater, its design discharge may be considered when calculating the peak outflow rate through the emergency spillway.

Pipe conduits under or through the dam shall meet the following requirements. The pipe shall be capable of withstanding external loading without yielding, buckling, or cracking. Flexible pipe strength shall not be less than that necessary to support the design load with a maximum of 5 percent deflection. The inlets and outlets shall be structurally sound and made of materials compatible with those of the pipe. All pipe joints shall be made watertight by the use of couplings, gaskets, caulking, or by welding.

For dams 20 ft or less in effective height, acceptable pipe materials are cast-iron, steel, corrugated steel or aluminum, asbestos-cement, concrete, plastic, vitrified clay with rubber gaskets, and cast-in-place reinforced concrete. Asbestos-cement, concrete, and vitrified clay pipe shall be laid in concrete bedding. Plastic pipe that will be exposed to direct sunlight shall be made of ultraviolet resistant materials and protected by coating or shielding, or provisions for replacement should be made as necessary. Connections of plastic pipe to less flexible pipe or structures must be designed to avoid stress concentrations that could rupture the plastic.

For dams more than 20 ft in effective height, conduits shall be plastic, reinforced concrete, cast-in-place reinforced concrete, corrugated steel or aluminum, or welded steel pipe. The maximum height of fill over any principal spillway steel or aluminum pipe must not exceed 25 ft. Pipe shall be watertight. The joints between sections of pipe shall be designed to remain watertight after joint elongation caused by foundation consolidation. Concrete pipe shall have concrete bedding or a concrete cradle, if required. Cantilever outlet sections, if used, shall be designed to withstand the cantilever load.

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Pipe supports shall be provided when needed. Other suitable devices such as a Saint Anthony Fall stilling basin or an impact basin may be used to provide a safe outlet. Protective coatings of asbestos-bonded, asphalt coated, or vinyl coating on galvanized corrugated metal pipe, or coal tar enamel on welded steel pipe should be provided in areas that have a history of pipe corrosion, or where the saturated soil resistivity is less than 4,000 ohms-cm, or where soil pH is lower than 5.

Specifications in tables 2 and 3 are to be followed for polyvinyl chloride (PVC), steel, and aluminum pipe.

Cathodic protection is to be provided for coated welded steel and galvanized corrugated metal pipe where soil and resistivity studies indicate that the pipe needs a protective coating, and where the need and importance of the structure warrant additional protection and longevity. If cathodic protection is not provided for in the original design and installation, electrical continuity in the form of joint-bridging straps should be considered on pipes that have protective coatings. Cathodic protection should be added later if monitoring indicates the need.

Practice standard 430-FF provides criteria for cathodic protection of welded steel pipe.

Seepage control along a pipe conduit spillway shall be provided if any of the following conditions exist:

1. The effective height of dam is greater than 15 ft.

2. The conduit is of smooth pipe larger than 8 in. in diameter.

3. The conduit is of corrugated pipe larger than 12 in. in diameter.

Table 2. Acceptable PVC pipe for use in earth dams[1]

Nominal pipe size	Schedule for standard dimension ratio (SDR)	Maximum depth of fill over pipe
in		ft
4 or less	Schedule 40	15
	Schedule 80	20
	SDR 26	10
6,8,10,12	Schedule 40	10
	Schedule 80	15
	SDR 26	10

[1]Polyvinyl chloride pipe, PVC 1120 or PVC 1220, conforming to ATSM-D-1785 or ATSM-D-2241.

Table 3. Minimum gage for corrugated metal pipe [2-2/3-in x ½-in corrugations][1]

Fill height (ft)	Minimum gauge for steel pipe with diameter (in) of ___					
	21 and less	24	30	36	42	48
1-15	16	16	16	14	12	10
15-20	16	16	16	14	12	10
20-25	16	16	14	12	10	10

Fill height (ft)	Minimum thickness (in) of aluminum pipe2 with diameter (in) of ___			
	21 and less	24	30	36
1-15	0.06	0.06	0.075	0.075
15-20	0.06	0.075	0.105	0.105
20-25	0.06	0.105	0.105	---3

1 Pipe with 6,8, and 10-in diameters has 1-1/2 in x ¼-in corrugations.

2 Riveted or helical fabrication.

3 Not permitted.

Seepage along pipes extending through the embankment shall be controlled by use of a filter and drainage diaphragm, unless it is determined that anti-seep collars will adequately serve the purpose

The drain is to consist of sand, meeting fine concrete aggregate requirements (at least 15% passing the No. 40 sieve but no more than 10% passing the No. 100 sieve). If unusual soil conditions exist, a special design analysis shall be made.

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The drain shall be a minimum of 2 ft thick and extend vertically upward and horizontally at least three times the pipe diameter, and vertically downward at least 18 in. beneath the conduit invert. The drain diaphragm shall be located immediately downstream of the cutoff trench, approximately parallel to the centerline of the dam.

The drain shall be outletted at the embankment downstream toe, preferably using a drain backfill envelope continuously along the pipe to where it exits the embankment. Protecting drain fill from surface erosion will be necessary.

When anti-seep collars are used in lieu of a drainage diaphragm, they shall have a watertight connection to the pipe. Maximum spacing shall be approximately 14 times the minimum projection of the collar measured perpendicular to the pipe. Collar material shall be compatible with pipe materials. The anti-seep collar(s) shall increase by 15% the seepage path along the pipe.

Closed conduit spillways designed for pressure flow must have adequate antivortex devices.

To prevent clogging of the conduit, an appropriate trash guard shall be installed at the inlet or riser.

A pipe with a suitable valve shall be provided to drain the pool area if needed for proper pond management or if required by State law. The principal spillway conduit may be used as a pond drain if it is located where it can perform this function.

Supply pipes through the dam to watering troughs and other appurtenances shall have an inside diameter of not less than 1-1/4 in.

Emergency spillways. Emergency spillways convey large flood flows safely past earth embankments.

An emergency spillway must be provided for each dam, unless the principal spillway is large enough to pass the peak discharge from the routed design hydrograph and the trash that comes to it without overtopping the dam. The following are minimum criteria for acceptable use of a closed conduit principal spillway without an emergency spillway: a conduit with a cross-sectional area of 3 ft2 or more, an inlet that will not clog, and an elbow designed to facilitate the passage of trash.

The minimum capacity of a natural or constructed emergency spillway shall be that required to pass the peak flow expected from a design storm of the frequency and duration shown in table 4, less any reduction creditable to conduit discharge and detention storage.

The emergency spillway shall safely pass the peak flow, or the storm runoff shall be routed through the reservoir. The routing shall start either with the water surface at the elevation of the crest of the principal spillway or at the water surface after 10 days' drawdown, whichever is higher. The 10-day drawdown shall be computed from the crest of the emergency spillway or from the elevation that would be attained if the entire design storm were impounded, whichever is lower. Emergency spillways shall provide for passing the design flow at a safe velocity to a point downstream where the dam will not be endangered.

Constructed emergency spillways are open channels that usually consist of an inlet channel, a control section, and an exit channel. They shall be trapezoidal and shall be located in undisturbed or compacted earth. The side slopes shall be stable for the material in which the spillway is to be constructed. For dams having an effective height exceeding 20 ft, the emergency spillway shall have a bottom width of not less than 10 ft.

Upstream from the control section, the inlet channel shall be level for the distance needed to protect and maintain the crest elevation of the spillway. The inlet channel may be curved to fit existing topography. The grade of the exit channel of a constructed emergency spillway shall fall within the range established by discharge requirements and permissible velocities.

Structural emergency spillways. If chutes or drops are used for principal spillways or principal emergency or emergency spillways, they shall be designed according to the principles set forth in the Engineering Field Manual for Conservation Practices and the National Engineering Handbook-Section 5, Hydraulics; Section 11, Drop Spillways;

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and Section 14, Chute Spillways. The minimum capacity of a structural spillway shall be that required to pass the peak flow expected from a design storm of the frequency and duration shown in table 4, less any reduction creditable to conduit discharge and detention storage.

Visual resource design. The visual design of ponds shall be carefully considered in areas of high public visibility and those associated with recreation. The underlying criterion for all visual design is appropriateness. The shape and form of ponds, excavated material, and plantings are to relate visually to their surroundings and to their function.

The embankment may be shaped to blend with the natural topography. The edge of the pond may be shaped so that it is generally curvilinear rather than rectangular. Excavated material can be shaped so that the final form is smooth, flowing, and fitting to the adjacent landscape rather than angular geometric mounds. If feasible, islands may be added for visual interest and to attract wildlife.

DESIGN CRITERIA FOR EXCAVATED PONDS

Runoff. Provisions shall be made for a pipe and emergency spillway if necessary. Runoff flow patterns shall be considered when locating the pit and placing the spoil (see table 4).

Side slopes. Side slopes of excavated ponds shall be stable and shall not be steeper than one horizontal to one vertical. If livestock will water directly from the pond, a watering ramp of ample width shall be provided. The ramp shall extend to the anticipated low water elevation at a slope no steeper than three horizontal to one vertical.

Perimeter form. If the structures are to be used for recreation or are highly visible to the public, the perimeter or edge should be curvilinear.

Inlet protection. If surface water enters the pond in a natural or excavated channel, the side slope of the pond shall be protected against erosion.

Excavated material. The material excavated from the pond shall be placed so that its weight will not endanger the stability of the pond side slopes and so that it will not be washed back into the pond by rainfall. It shall be disposed of in one of the following ways:

1. Uniformly spread to a height that does not exceed 3 ft, with the top graded to a continuous slope away from the pond.

2. Uniformly placed or shaped reasonably well, with side slopes assuming a natural angle of repose. The excavated material will be placed at a distance equal to the depth of the pond but not less than 12 ft from the edge of the pond.

3. Shaped to a designed form that blends visually with the landscape.

4. Used for low embankment and leveling.

5. Hauled away.

Table 4. Minimum spillway capacity

			Minimum design storm[2]	
Drainage area	Effective ht. of dam[1]	Storage	Frequency	Minimum duration
Acre	Ft	Ac-ft	Yr	Hr
20 or less	20 or less	< than 50	10	24
20 or less	> than 20	< than 50	25	24
> than 20		< than 50	25	24
All others			50	24

1. As defined under "Scope."
2. Select rain distribution based on climatological region.

PLANS AND SPECIFICATIONS

Plans and specifications for installing ponds shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose.

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APPENDIX II

Additional Resources

Resource Type	*To Receive a Copy:*
Permitting	
Water Rights in Montana, Department of Natural Resources and Conservation Helena, 2004	(406) 444-6610 www.dnrc.state.mt.us/wrd/home.htm
A Guide to Stream Permitting in Montana, Montana Association of Conservation Districts Helena, 1997	(406) 444-6669 www.dnrc.state.mt.us/cardd/cardd.html
Pond Planning	
POND-er-ing? An Aquatic Resource Guide for Montana Landowners, Montana Watercourse, 2004	(406) 994-6671 www.mtwatercourse.org
PONDS – Planning, Design, and Construction Agriculture Handbook 590 Natural Resources Conservation Service	Included on CD -- Rear pocket of binder
Fish Stocking	
A Guide for Building and Managing Private Fish Ponds in Montana, Montana Fish, Wildlife & Parks Helena, 2004	*(406) 444-2449* www.fwp.state.mt.us
Other References	
Natural Resources Conservation Services (NRCS) Technical References	www.nrcs.usda.gov/technical/ENG www.info.usda.gov/CED/ Search: "dams"
Montana NRCS link	www.mt.nrcs.usda.gov/technical/eng/

APPENDIX II