

MANUAL ON CORRUGATED METAL PIPE IN DAMS FOR MONTANA DAM OWNERS

Problem Identification and Evaluation, Inspection, Rehabilitation, Repair, and Replacement



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Prepared by:



**MANUAL ON CORRUGATED METAL PIPE IN EMBANKMENT DAMS
FOR MONTANA DAM OWNERS**
PROBLEM IDENTIFICATION AND EVALUATION, INSPECTION, REHABILITATION,
REPAIR, AND REPLACEMENT

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SECTION 1 - INTRODUCTION

This manual is intended to provide practical guidance and information to dam owners and users in Montana, specifically in regard to issues surrounding corrugated metal pipe (CMP) and its use in embankment dams. This manual is not a regulatory document, nor is it an exhaustive reference on the subject.

Undetected corrosion of CMPs, among other problems, is one of the primary causes of dam failure in Montana. Other issues with CMP include: abrasion, cavitation, and structural failure due to inadequate backfill. Each of these issues, left undetected, can ultimately lead to the failure of the embankment and loss of the contents of the reservoir. Dam failure can result in economic loss, environmental damage, disruption of lifeline facilities (e.g. roads and bridges), and even loss of life (FEMA 2005).

One piece of good news is that “often these pipes show distress well in advance of ultimate failure” (Kula, Zamensky and King 2000). This manual provides useful information to educate dam owners and operators on inspection techniques and practices. It also discusses the basic composition and behavior of CMP and describes the potential failure mechanisms. Once a problem has been identified through inspection, a decision must be made whether to repair, rehabilitate, or replace the conduit. Several alternatives will be presented, and advantages, disadvantages, costs, and feasibility of each are discussed. The objective of this manual is to help to identify potential problems in advance of failure and to present cost effective methods for investigating and rehabilitating CMP in embankment dams.



Figure 1: Photo of a dam failure in Garfield County (MT DNRC).

SECTION 2 - UNDERSTANDING CORRUGATED METAL PIPE AND ITS APPLICATION IN DAMS

2.1 BRIEF HISTORY OF CORRUGATED METAL PIPE IN DAMS

According to the National Inventory of Dams, maintained by the U.S. Army Corps of Engineers (USACE), there are a total of 2917 dams 50 acre feet or larger in the state of Montana. See Figure 2 below for a map showing the locations of the dams.

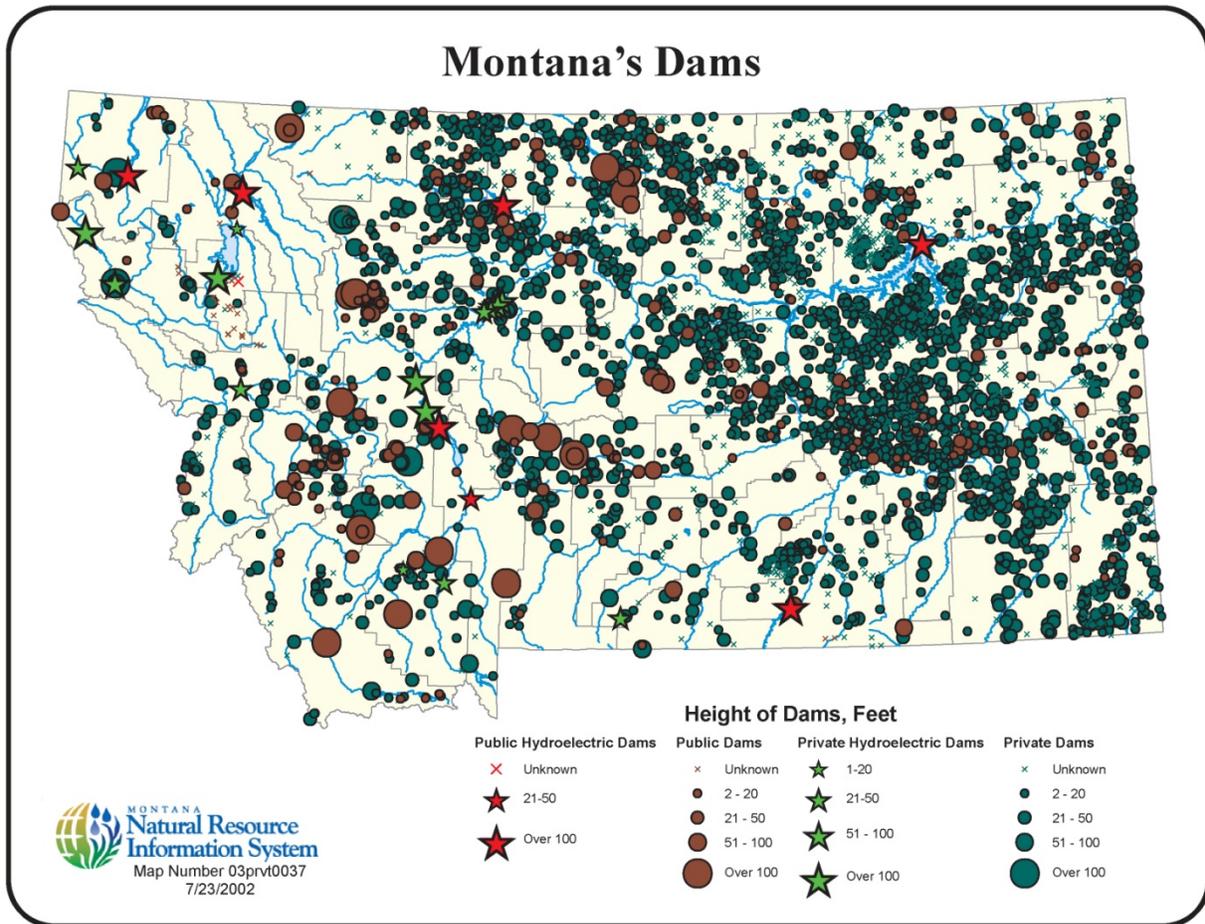


Figure 2: Map of dams across the state of Montana (Montana Natural Resource Information System).

Of these dams, the vast majority are privately owned embankment dams, constructed between 1930 and 1980. See Figures 3, 4, and 5 below.

Dams by Primary Owner Type

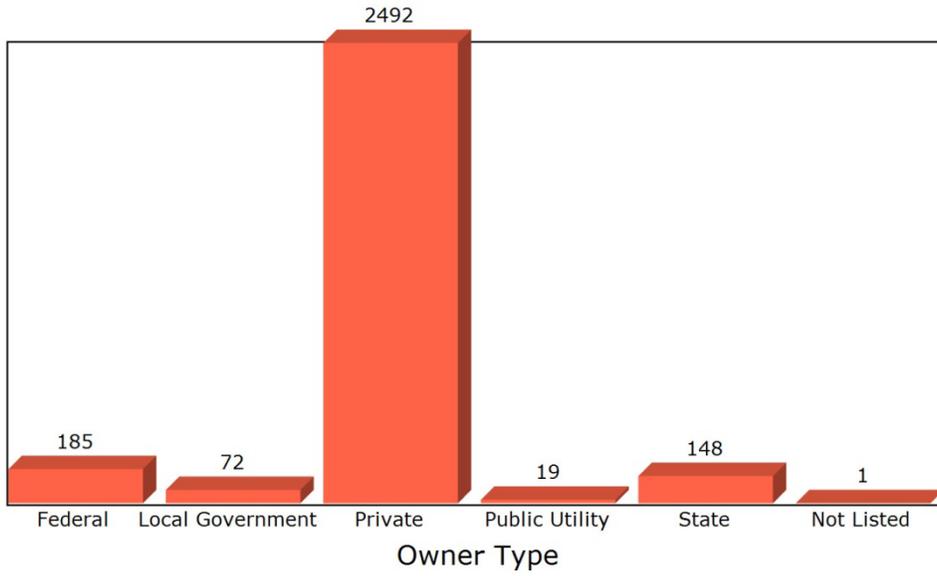


Figure 3: Graph of dams in Montana categorized by primary owner type (USACE, National Inventory of Dams).

Dams By Primary Type

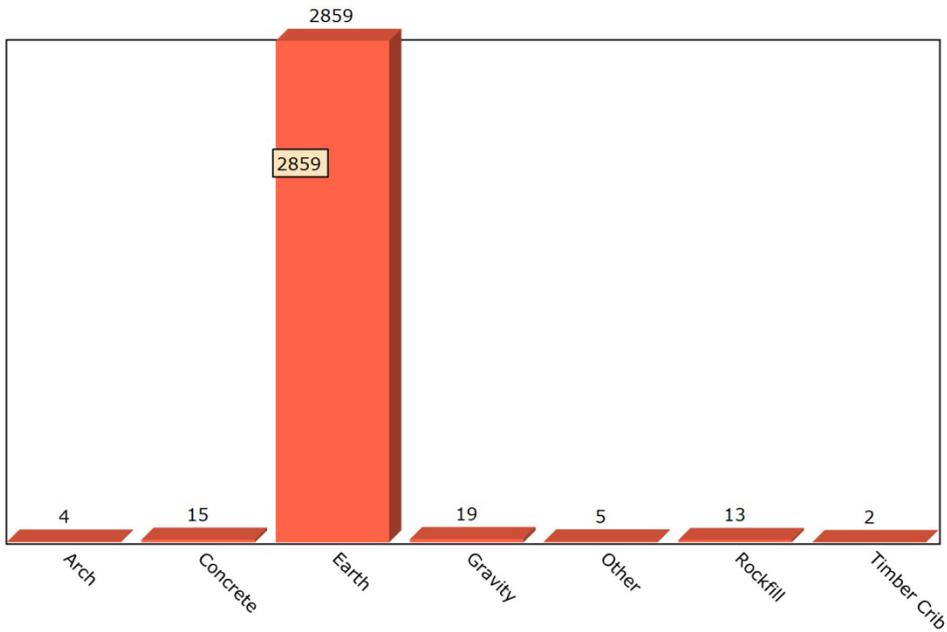


Figure 4: Graph of dams in Montana categorized by primary type (USACE, National Inventory of Dams).

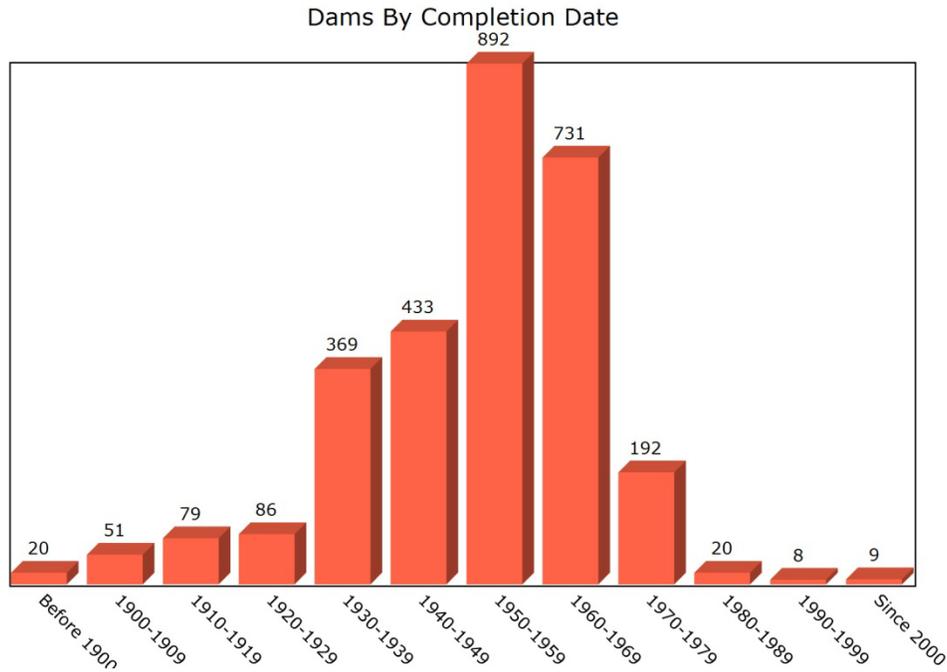


Figure 5: Graph of dams in Montana categorized by completion date (USACE, National Inventory of Dams).

CMPs have been historically used for the outlet works in many of the smaller dams throughout the state. Studies “suggest that the undetected corrosion or other forms of distress in the CMP spillway system may be an initiator of embankment piping [see Section 2.4] and possible breach of the dam, or the development of a significant, uncontrolled leak that results in draining of the reservoir” (McCann 1999). The age of these dams, combined with the inherent deterioration of the CMP outlet works, create a significant area of concern for dam owners, regulators, and engineers (Kula, Zamensky and King 2000).

A 1998 survey of State dam safety programs (with 14 states responding to the survey) estimated that 1,115 embankment dams will need repair over the next 10 years. The graph in Figure 6 shows the material makeup for the conduits in these dams.

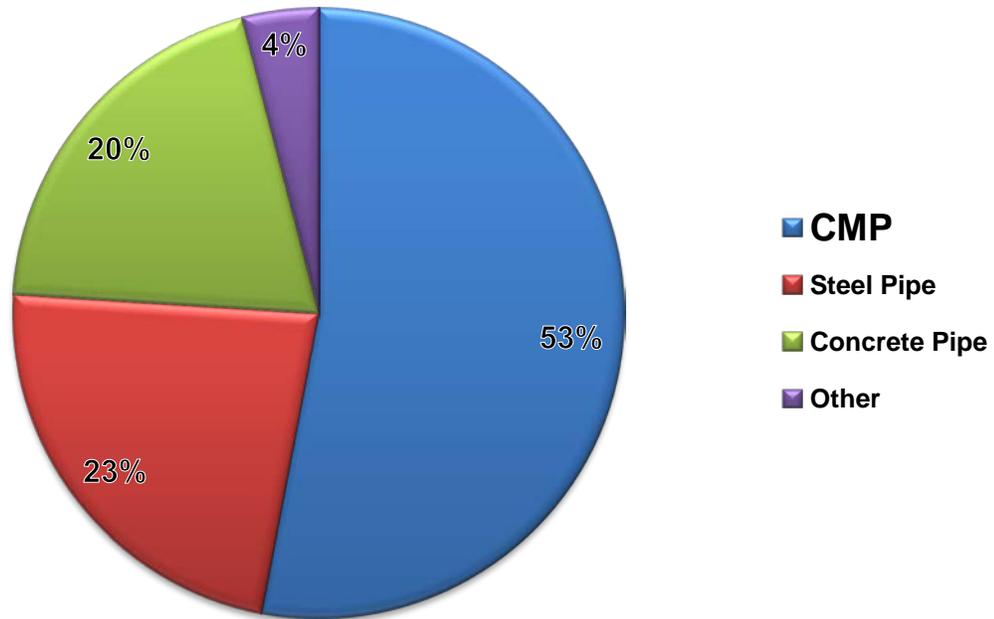


Figure 6: Composition of conduits in embankment dams needing repair from 1998 study (FEMA 2005).

In observed failures of large embankment dams, it has been determined that about one-half are attributable to some form of piping. Approximately half of these piping failures are known to have initiated around or near a conduit. See Figure 7 below.

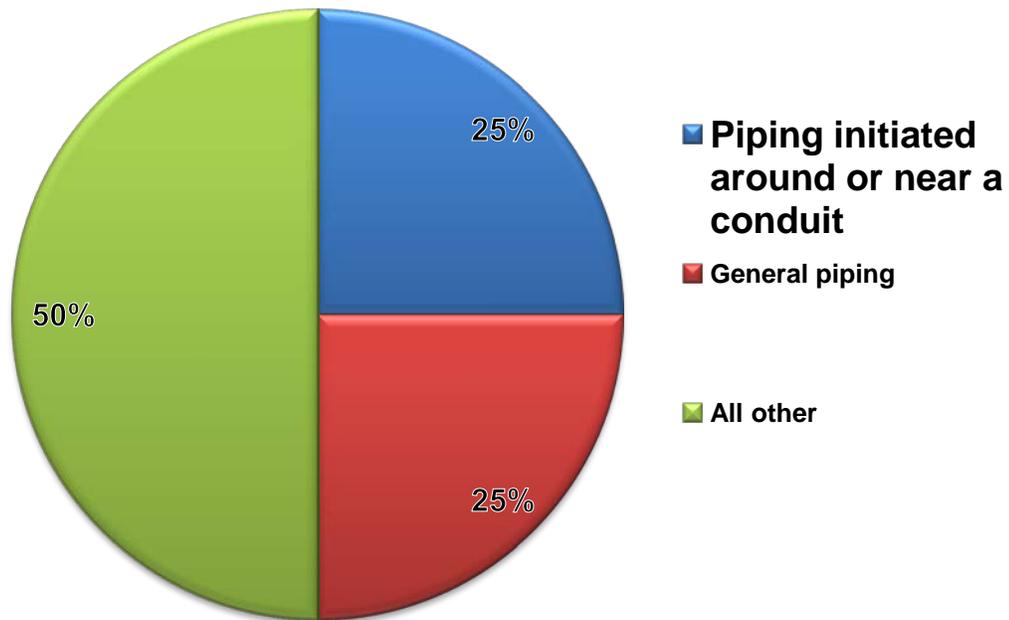


Figure 7: Failure mode of large embankment dams.

This graph shows that approximately 25% of all dam failures are a result of piping associated with conduits (Foster, Fell and Spannagle 2000).

History and statistics show that many problems with dams are associated with the conduit and outlet works. CMP conduits and outlet works amplify the problem and increase the risk.

2.2 TYPES OF PROBLEMS ASSOCIATED WITH CMP

CMPs are utilized for different features of dams including conduits, risers, spillways, and outlet structures. CMP is advantageous because it is lightweight and allows for easy installation without the use of heavy equipment. However, there are many serious disadvantages as well. Typical problems seen with CMP are: corrosion of the main body of pipe and joints, corrosion between drop tower and conduit, joint separation, and structural failure due to inadequate backfill. Each of these problems is described below in further detail.

Corrosion of main body of pipe and joints

Uncoated CMP is susceptible to corrosion from a number of sources: soil, groundwater, and water in the pipe. Corrosion is defined as the “deterioration or breakdown of metal because of a reaction with its environment” (Ohio Department of Natural Resources 1999); the mechanics of corrosion are further described in Section 2.3. When the corrosion advances to a point where holes begin to develop, water flows into or out of the pipe and begins to erode the soil around the pipe. The Figures below show what corrosion can do to the body of the pipe.

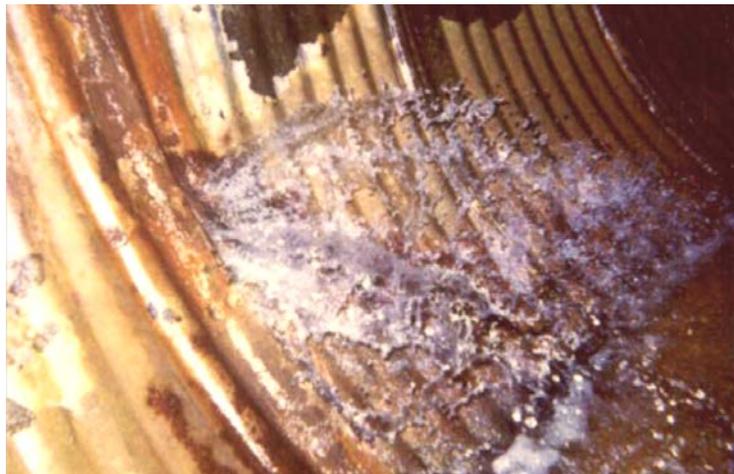


Figure 8: Photo of corrosion at joints (FEMA 2005).



Figure 9: Photos of corrosion of CMP pipes in two Montana dams (MT DNRC).

Corrosion at connection between drop tower and conduit

Corrosion is also a concern where the drop tower connects to the outlet conduit. A dam configuration like this is shown in Figure 10 below.

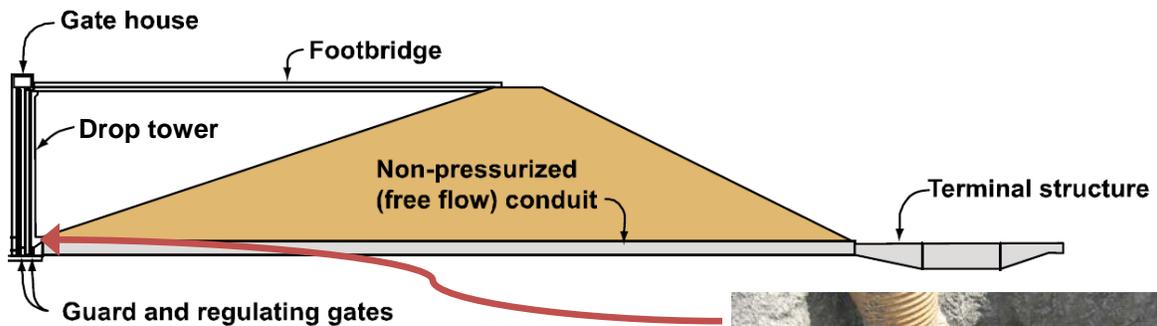


Figure 10: Corrosion at connection between drop tower and conduit. Figure above courtesy of FEMA. Photo at right: Failed dam in Petroleum County (MT DNRC).



Joint separation

Joint separation, which leads to leaking joints, is mostly attributable to improper construction techniques. These include: damaged pipe section ends from transport or installation, gaskets not used at joints, or helically corrugated pipe ends may not have been re-rolled to provide for proper joint contact (Kula, Zamensky and King 2000). All of these issues may ultimately lead to water leaking into or out of the pipe and eroding the soil adjacent to the pipe. See Figure 11 below for photos showing examples of joint separation.

Structural failure due to inadequate backfill

Unlike rigid pipes (e.g. concrete, ductile iron), CMPs obtain their structural support from the surrounding soils. “Because they are flexible, they are designed to deform somewhat against the adjacent backfill and mobilize lateral resistance of the soil. This lateral resistance acting against the sides of the pipe stiffens the shell and provides its vertical load carrying capacity” (Kula, Zamensky and King 2000). If the backfill is not adequately compacted, the pipe can deform, resulting in structural failure or even collapse. See Figure 12 and Figure 13 for photos showing examples of pipe deformation.



Figure 11: Photos of joint separation (U.S. Department of Transportation, FHWA 2010).



Figure 12: Photo of CMP structural failure and collapse (U.S. Department of Transportation, FHWA 2010).



Figure 13: Photo of collapsed outlet works in a Chouteau County dam (MT DNRC).

The problems with CMP just described were separated for clarity; however, these problems can be and are often interrelated. “For instance, as the pipe corrodes with time, its effective wall thickness will decrease. As this occurs, the potential for problems will be increased if the quality of the backfill adjacent to the pipe is not adequate to provide the lateral force necessary to resist the vertical loads from the embankment. This situation can result in excessive cross-sectional deformations and the eventual collapse of the pipe” (Kula, Zamensky and King 2000).

2.3 CORRUGATED METAL PIPE DESCRIBED

Composition of CMP

Corrugated “metal” pipe is usually comprised of steel, as opposed to some other metal such as aluminum. However, it is still generically referred to as CMP. CMP is available in a variety of gages (thickness), shapes, and sizes. CMP “has been used successfully since the late 1800s” (National Corrugated Steel Pipe Association 2008). If a CMP was fabricated and installed with just bare steel, the design life of the pipe would be drastically shortened, as bare steel is very susceptible to corrosion. To counteract this, there are several ways that a CMP can be coated. Different coating types are described below in further detail.

- **Coatings and design life**

- Galvanizing

Galvanizing is the process of applying a protective zinc coating to steel in order to prevent rusting. This is the most common type of coating seen on CMPs and has been in use for the longest period of time.

- Aluminized Type 2 (ALT2)

ALT2 was introduced as an alternative coating in 1948 (National Corrugated Steel Pipe Association 2008). It utilizes a pure aluminum coating and allows the CMP to perform in wider ranges of pH and resistivity.

- Polymer Coating

Polymeric coatings were introduced in the 1970’s (National Corrugated Steel Pipe Association 2008) and come in several varieties, including ethylene acrylic or polyvinyl chloride plastisol (PVC). The polymer coating is applied over the galvanized coating and provides excellent adhesion to the base steel, as well as extended corrosion and abrasion resistance.



Figure 14: Photo of bituminous coated CMP from a dam in Judith Basin County, installed circa 1950 (MT DNRC)



Figure 15: Photo of polymer coated CMP used for replacement of outlet pipe in a Fergus County dam (MT DNRC)



Figure 16: Photo of deteriorated bituminous coating on outlet pipe in a Park County dam (MT DNRC)

- Asphalt Coating

Asphalt (or bituminous) coatings have been used historically and have been very effective, as shown in Figure 14 and Figure 16. These pipes survived over 60 years while still maintaining their structure. Asphalt coatings are applied after the pipe is manufactured, and therefore, are limited to larger diameter pipes which allow for man-entry.

There are additional coatings available for extremely abrasive situations. These include asphalt paved, concrete paved, and aramid fiber asphalt coated. A discussion of these coatings is beyond the scope of this manual.

“All coatings and linings have some minor flaws (holidays). Corrosion tends to concentrate at these flaws, since water can seep between the coating or lining and the base metal, can become trapped, increasing the rate of corrosion. Thus, it may be possible for a coated CMP to become deteriorated in less time than an uncoated CMP in the same environment” (FEMA 2005). Table 1 below shows estimated service life for CMP for the different coatings described above. The pH and Resistivity (r) of both the surrounding soil and water affect the pipe. Resistivity and pH are further described below.

It should be noted that many of these coatings were not available or common at the time many older dams in Montana were constructed. “Therefore, the expected service life of CMPs in older dams will vary and should be expected to be less than CMPs installed in compliance with today’s standards” (Kula, Zamensky and King 2000).

Estimated Material Service Life for CMP		
CMP Material	Estimate Service Life	Site Environmental Conditions ¹
Galvanized CMP	Average 50 years	$6 \leq \text{pH} \leq 10$ $2000 \leq r \leq 10,000$
Aluminized Type 2 CMP (ALT2)	Minimum 75 years	$5 \leq \text{pH} \leq 9$ $r > 1500$
Polymer Coated CMP	Minimum 100 years	$5 \leq \text{pH} \leq 9$ $r > 1500$
	Minimum 75 years	$4 \leq \text{pH} \leq 9$ $r > 1500$
	Minimum 50 years	$3 \leq \text{pH} \leq 12$ $r > 1500$
Bituminous Coated	Adds 2-20 years to galvanized pipe	$4 \leq \text{pH} \leq 10$ $r > 2000$

¹r = resistivity, units = ohm-cm

Table 1: Estimated Material Service Life for CMP (National Corrugated Steel Pipe Association 2008).

Deterioration of CMP

The deterioration of CMP, which eventually leads to the problems previously described, is dependent upon and caused by a number of factors. Corrosion, abrasion, and cavitation are the three primary causes of the deterioration of the pipe; they are described in further detail below.

- **Galvanic corrosion**

“Corrosion is the destructive attack on conduit materials by electrochemical reaction to the environment... The soil and water surrounding the conduit, and water flowing through the conduit can affect the rate of corrosion” (FEMA 2005). The invert (bottom) of a CMP is the most prone to corrosion, since it is exposed to the flow of water for the longest period of time. Over time, corrosion of the CMP will result in the reduction of wall thickness, formation of pipe perforations (holes), and the eventual collapse of the CMP. The following factors will influence corrosion and are described in further detail below.

- **Soil Resistivity**

Corrosion involves the flowing of electrical current from one location to another. “The ability of soils surrounding conduits to conduct electrical particles can affect their tendency to corrode a conduit. *Resistivity* is a measure of the resistance [of the soil] to current flow of a material” (FEMA 2005). Therefore, the *higher* the resistivity value of a soil, the *less* likely it is to corrode a conduit.

- **Oxygen Content**

Increasing levels of dissolved oxygen can accelerate corrosion (FEMA 2005).

- **Soluble Salts**

Salts that become ionized can decrease the resistivity of a soil (FEMA 2005).

- **Moisture Content**

Soils that “hold” water are typically more corrosive than soils that drain water. A sandy soil would tend to be less corrosive than a clayey soil.

- **Acidity (pH)**

The majority of soils fall into a pH range of 6 to 8, which is neutral. Soils that have a lower pH (more acidic or “hot”) tend to be more corrosive.

- **Abrasion**

Abrasion is defined as the process of scraping or wearing down by friction. In CMPs, it is primarily a concern for coatings on the pipe. “Abrasion is caused by water flowing through a conduit at high velocities and containing silts, sands, gravels, or stones” (FEMA 2005). When a coating becomes damaged, leaving the bare steel open to direct contact with water, the potential for corrosion increases substantially.

- **Cavitation**

Cavitation is a technical term for the “boiling” of the water, except that it occurs far below the boiling temperature of water. In the right conditions of high velocities and misalignments or discontinuities in the pipe, the water actually bubbles. “When these bubbles travel downstream and collapse next to the conduit surface, the high pressure impact removes small particles of the conduit surface (pitting)” (FEMA 2005). This process continues and builds on itself and can eventually damage the conduit.



Figure 17: Photo of corrosion in a CMP outlet pipe in a Missoula County dam (MT DNRC).

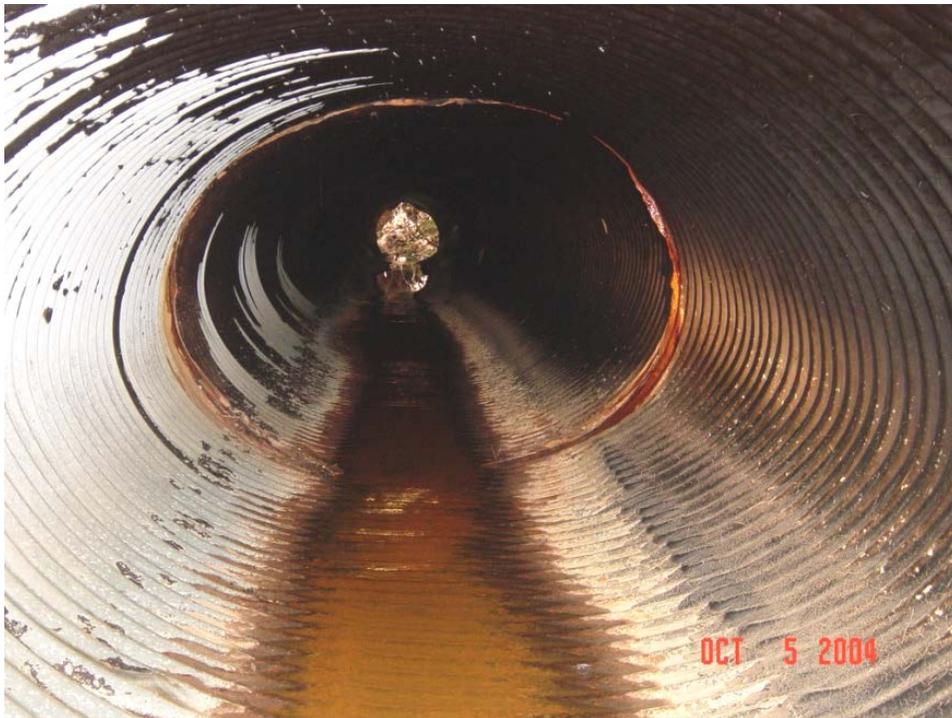


Figure 18: Photo of damage to polymer coating on a CMP from abrasion (source unknown).



Figure 19: Photo of cavitation damage on outlet works at Beaver Creek Dam, Hill County, Montana (photo courtesy of Great West Engineering, Inc.)

2.4 FAILURE MODES RELATED TO CONDUITS

All of the problems with CMP described above in Section 2.2 can ultimately lead to the failure of the dam. When water escapes the conduit and enters the surrounding soil, it increases the seepage pressure from what is normally “seen” by those soils. The water can develop flow paths through the soil and can erode the fill. The process by which the soil erodes through the dam has been termed “piping”. Piping is a general term, and there are different types of piping that distinguish between the mechanisms by which the water moves through the soil. Figure 21 and Figure 22 below show schematics of the piping process.



Figure 20: Photo of a dam failure in Chouteau County. Failure was caused by piping around outlet pipe (MT DNRC).

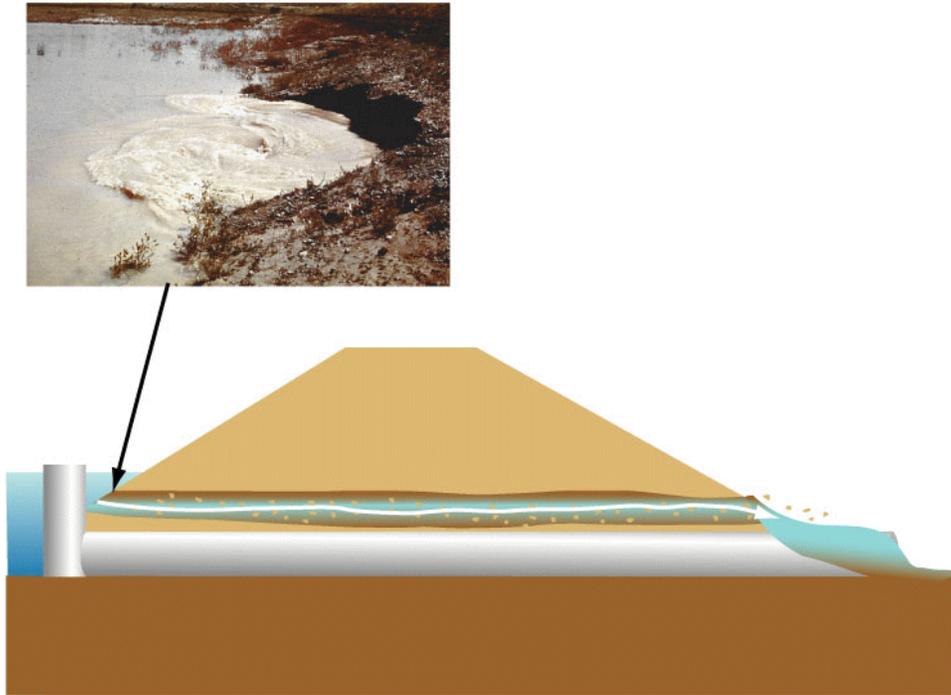


Figure 21: Schematic of piping near a conduit. A vortex may form where the water from the reservoir enters the fracture (FEMA 2005).

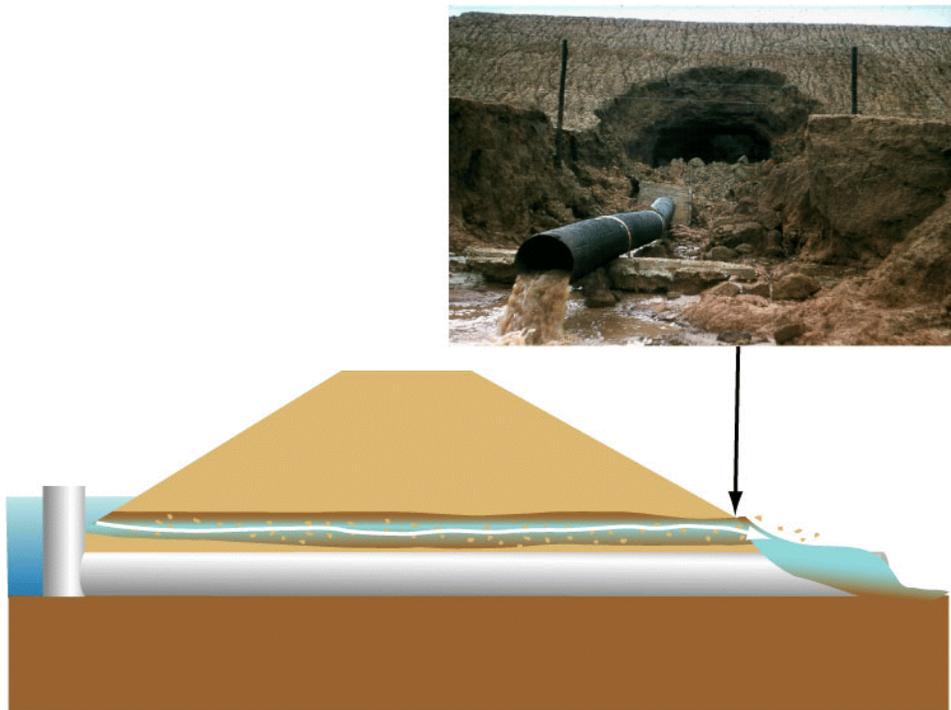


Figure 22: Schematic of piping near a conduit. Photo of a tunnel-shaped void at outlet (FEMA 2005).

Piping in dams can occur apart from conduits; any weakness or “soft spot” in the embankment can be a vulnerable point for piping to begin. The discussions in this manual will focus only on piping associated with conduits. Two different “modes” of failure associated with conduits are described below.

Piping of soils into a non-pressurized conduit

Most, if not all, CMP conduits used in embankment dams are non-pressurized. The joining mechanism for different sections of CMP does not allow for a pressurized seal. If the CMP deteriorates to a point where voids in the pipe body or gaps in the pipe joints develop, soil particles may begin to seep into the conduit. The sequence of events for this failure mode is outlined below.

1. The reservoir is filled, and seepage develops through the embankment (no dam is waterproof).
2. Seepage enters holes or gaps in the CMP and carries soil particles with it.
3. Preferential flow paths develop through the soil, and water from the reservoir flows along these “cracks”.
4. Soil continues to be eroded, and a tunnel or sinkholes may develop.
5. Reservoir loses ability to hold water, and a complete breach may occur.



Figure 23: Photo of piping around culvert at outlet of a Ravalli County dam (MT DNRC).

See Figure 24 below, which shows a schematic of this failure mode.

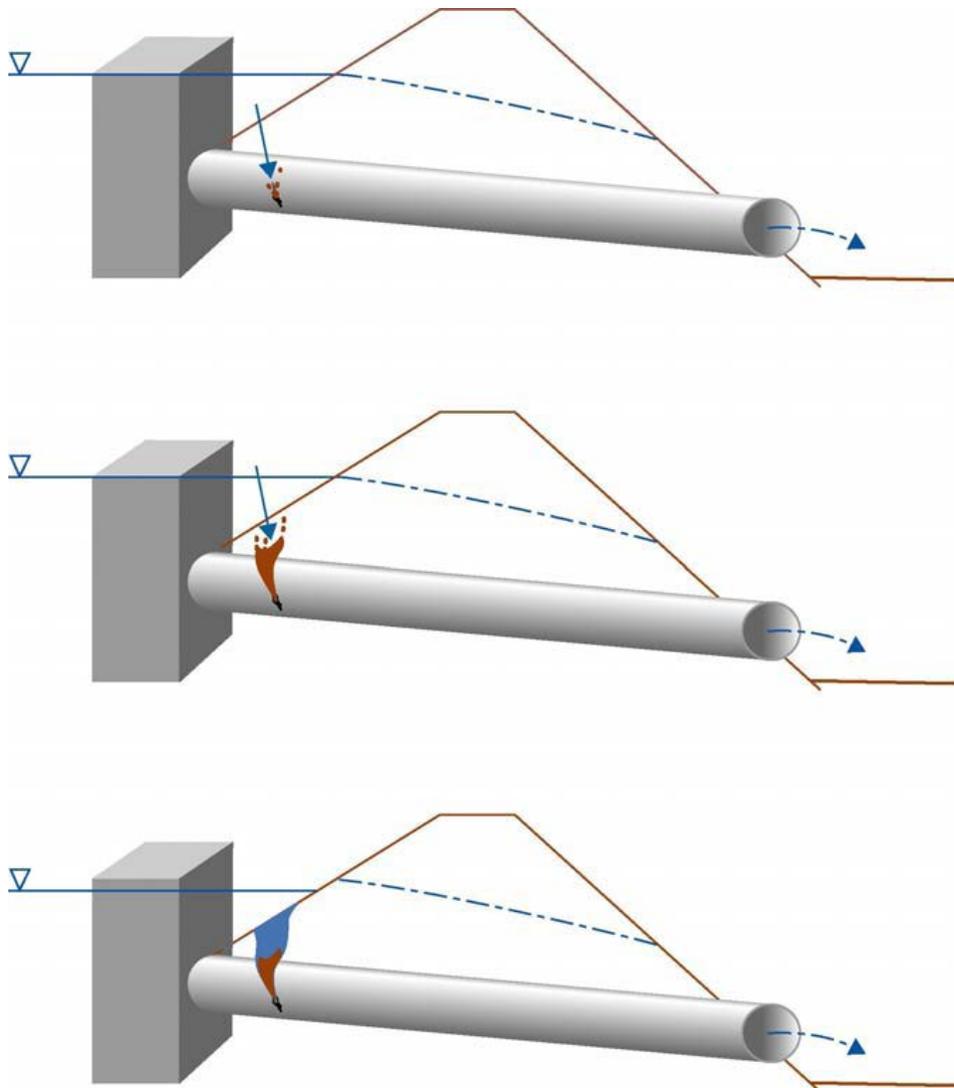


Figure 24: Schematic of piping surrounding a defect in a non-pressurized conduit (FEMA 2005).

Piping of soils along the outside of a conduit

Conduits inherently introduce an irregularity through an embankment. In addition, it is difficult to uniformly compact soils surrounding a conduit with respect to the rest of the embankment. Inadequate compaction often creates low density zones immediately adjacent to conduits, which create pathways for seepage. See Figure 25 and Figure 26 below.

Another construction issue related to compaction near the conduit is when the compactive energy actually lifts the conduit, creating a low density zone beneath. This also creates a pathway for seepage. See Figure 27 below.

The issues described above allow water to seep from the reservoir along the outside of the conduit. The sequence of events for this failure mode is outlined below.

1. Construction related compaction issues create a low density zone of soil adjacent to the conduit.
2. Seepage from the reservoir flows along and through this zone.
3. Preferential flow paths develop through the soil, and water from the reservoir flows along these “cracks”.
4. Soil continues to be eroded, and a tunnel may develop.
5. Reservoir loses ability to hold water and a complete breach may occur.

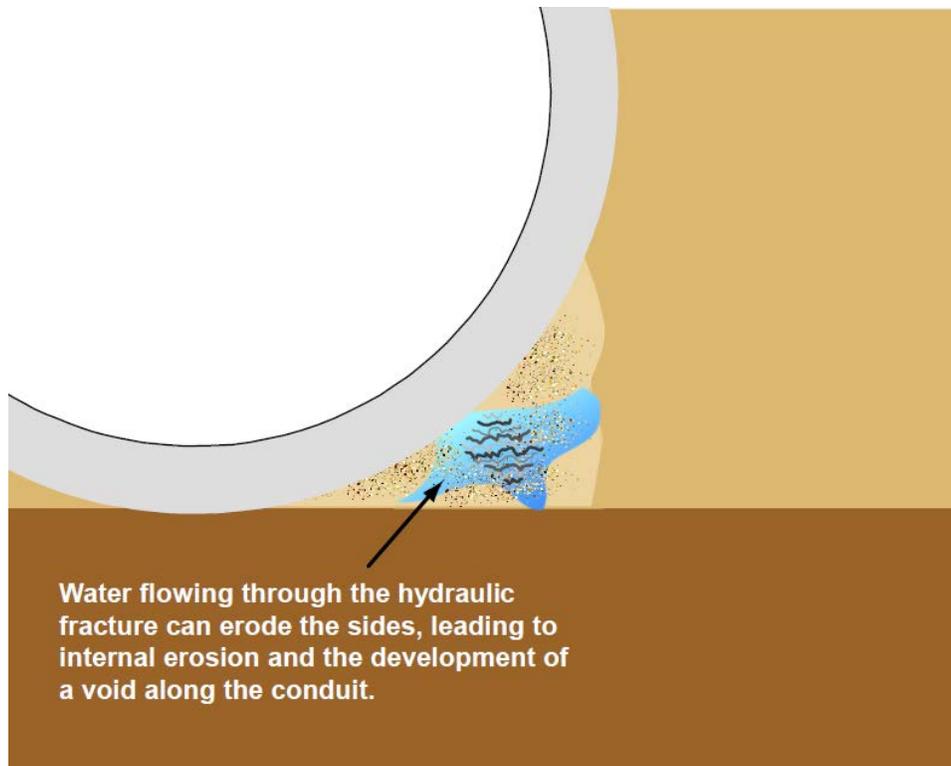


Figure 25: Figure of poor compaction of soil around conduit (FEMA 2005).



Figure 26: Photo of piping resulting from poor compaction around conduit (FEMA 2005).

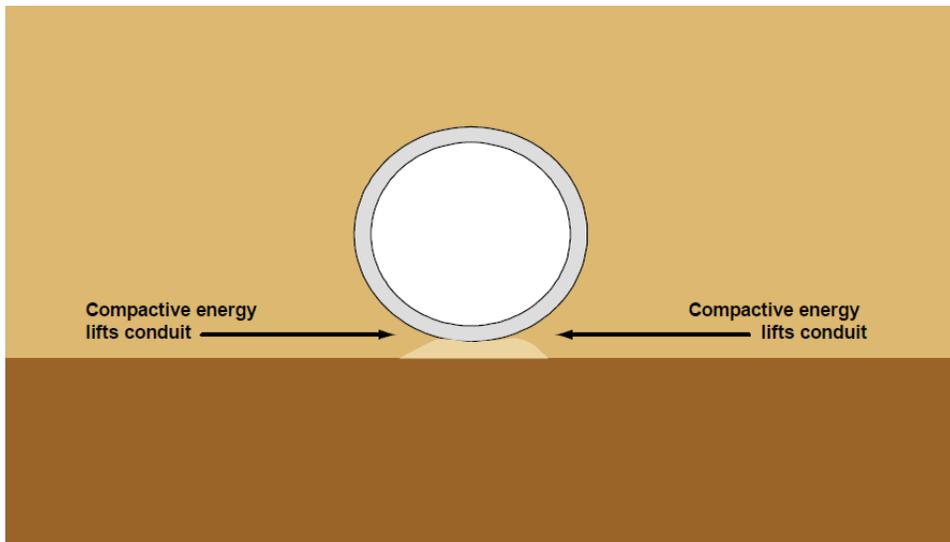


Figure 27: Figure showing how compactive energy can raise conduit (FEMA 2005).

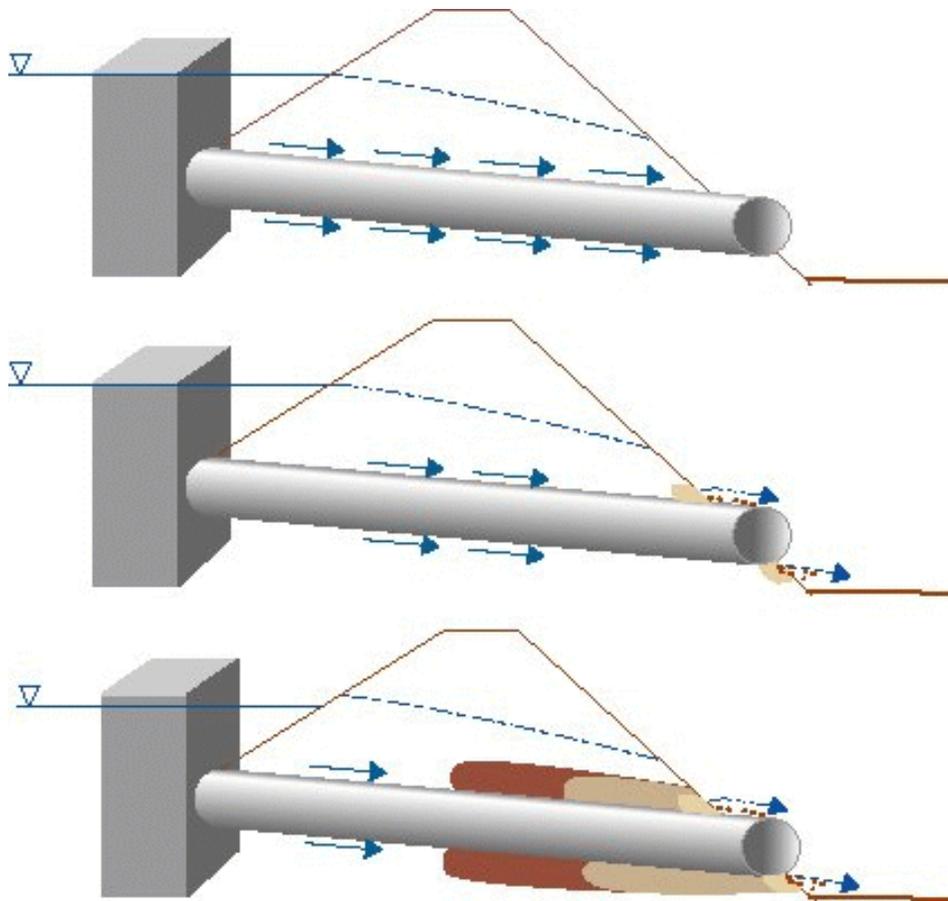


Figure 28: Schematic showing piping at the interface between the conduit and surrounding soils (FEMA 2005).

2.5 CONSEQUENCES OF DAM FAILURE

According to the *2010 Update to the State of Montana Multi-Hazard Mitigation Plan and Statewide Hazard Assessment* published by the Montana Disaster and Emergency Services, there have been at least 12 recorded dam failures and incidents in Montana from 1908 to 2002, which have resulted in “34 deaths and extensive property damage.” In actuality, there have been numerous of dam failures across the state, which have not been recorded or publicized due their relatively small impact or association with other natural disasters taking place. Just during the flooding of 2011, 100’s of small dams failed in the Musselshell River drainage. The Association of State Dam Safety Officials keeps a list of dam failures across the nation. While this list is not comprehensive, it records nearly 200 failures and incidents from 1869 to present, with varying degrees of fatalities and property damage (Association of State Dam Safety Officials n.d.). Dam failure and incidents can have a number of consequences. Several are listed below:

-
- **Loss of life**
 - **Disruption of lifeline facilities**
 - Roads and bridges
 - **Flooding**
 - **Property damage**
 - **Loss of commercial use**
 - Irrigation
 - Power generation
 - **Loss of recreational use**
 - Fishing
 - Boating
 - Camping
 - **Environmental damage**
 - **Reimbursement of County Expenses**

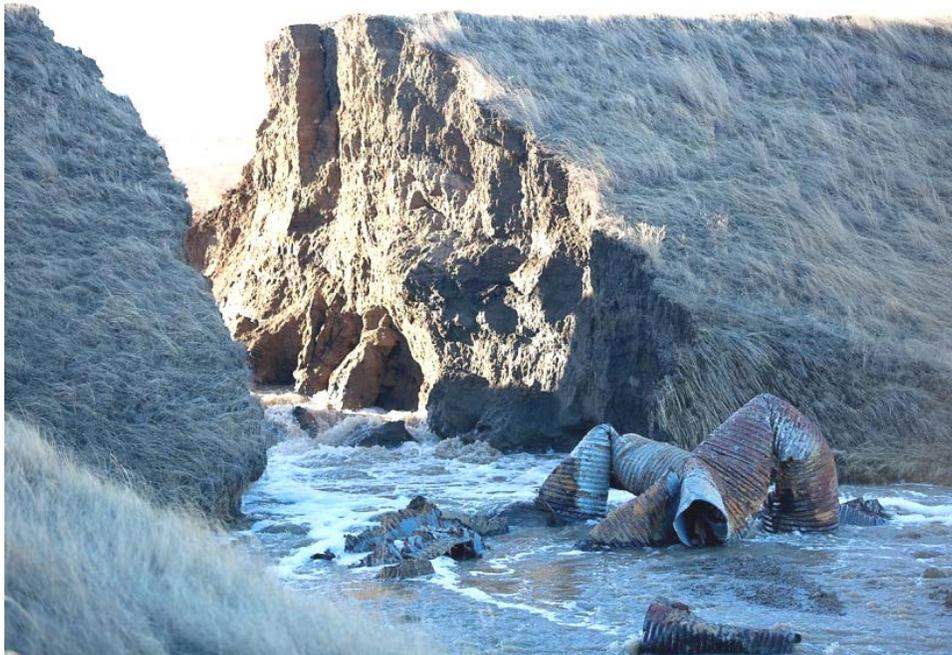


Figure 29: Photo of a Choteau County dam failure, (MT DNRC).

SECTION 3 - INSPECTION OF CORRUGATED METAL PIPE CONDUITS AND RELATED PROBLEMS

The importance of regular inspection on embankment dams cannot be overemphasized. An effective inspection program is essential for identifying problems and providing safe maintenance of a dam.

3.1 PREPARING FOR INSPECTION

Review existing historical information on dam

A thorough review of existing information on the dam is a very important first step, especially if the inspector is not familiar with the dam. Several pieces of information to review are listed below.

- **Sketches**
- **Previous inspection data**
- **Construction photos**
- **Reservoir operation records**
- **Plans and specifications**
- **As-builts**

Inspection Forms

Dam owners may contact a Dam Safety Program Regional Office Engineer or a local Natural Resources Conservation Service (NRCS) office to obtain information and inspection forms. See Appendix A for a list of contacts.

3.2 EXTERIOR INSPECTION

Inspecting areas above and surrounding the CMP can provide good insight as to the condition of the CMP. “The general technique [for exterior inspection] is to walk over the slopes and crest as many times as is necessary in order to see the entire surface area clearly. From a given point on the dam, small details can usually be seen for a distance of perhaps 10 to 30 feet in any direction, depending on the roughness of the surface, vegetation, or other surface conditions. Therefore, to ensure that the entire surface of a dam has been covered, several passes must be made. It is not really that important what approach is used, as long as it is systematic such that all of the surface area is covered” (Veesaert n.d.). It is recommended

that a minimum of four complete passes be made: 1) inlet toe, 2) upstream crest, 3) downstream crest, and 4) downstream toe. Several areas on the exterior of the dam and conduit should be inspected and are listed below.

Areas of seepage

Wet areas that are noticed on the downstream face of the embankment should be flagged and monitored. If seepage is actually flowing from the dam, actions should be taken to measure the quantity of flow. “Measurement of flow by a stopwatch and bucket is a simple way to collect flow information. Installation of a weir and staff gauge is preferred for more uniform data collection under longer term conditions” (FEMA 2005). See Figures 31-34 below.

Sediment or turbidity in culvert discharge

Water flowing in the vicinity of the conduit should be observed to see if it is cloudy or has soil particles in it; this could be a sign of piping. See Figure 35 below.

Deposits of sand at the exit point of seepage

This is another sign that seepage through the dam is eroding the soil along the flow path.

Depressions, sinkholes

These are usually an indication that piping is occurring. See Figures 36-38 below.

Changes in reservoir pool level

Any sudden changes in reservoir pool level should be noted. The rate of seepage should also be compared to reservoir pool level. “For example, an increase in the seepage rate while the pool level is constant could be an indication of piping” (FEMA 2005).

Changes in dam crest alignment

This can produce areas of low embankment strength and discontinuity, which can create paths for seepage.

Deep rooted vegetation

Large tree roots can create seepage paths. Bushes can obscure visual inspection and harbor rodents.

Cracks

Cracks allow water to enter the embankment in concentrated areas.

Animal burrows

Rodents burrow in the embankment and create natural paths for the water to follow. See Figure 39 below.

The Garfield County dam near Jordan, Montana failed in June of 2002. The failure was believed to have been caused by a large rodent hole, accompanied by intense rainfall.



Figure 30: Photo of a Garfield County dam failure and the culprit (MT DNRC).

Check exposed areas of CMP for weathering and/or chemical deterioration

Deterioration of the exterior of the CMP gives good indication that the same may be occurring on the interior of the pipe. See Figure 40 below.

Whirlpools

Whirlpools can indicate that there is a problem with the drop tower. See Figure 41 below.

Reductions in discharge capacity

A reduction in discharge capacity of the conduit could indicate that there is a problem with the CMP. For example, the culvert may have collapsed due to structural failure.



Figure 31: Seepage at the downstream face of an embankment dam (FEMA 2005).



Figure 32: Photo of seepage below dam (Fischer, Tips and Tricks for Inspecting Dams and Canals n.d.).



Figure 33: Photo of seepage and sinkhole (Fischer, Tips and Tricks for Inspecting Dams and Canals n.d.).



Figure 34: Photo of seepage and flow measurement weir (Fischer, Tips and Tricks for Inspecting Dams and Canals n.d.).



Figure 35: Photo of off-color discharge from conduit in a Cascade County dam (MT DNRC).



Figure 36: Photo of sinkhole at conduit outlet in a Chouteau County dam (MT DNRC).



Figure 37: Photo of developing sinkhole at dam in Granite County. Caused by piping around deteriorated CMP drain pipe (MT DNRC).



Figure 38: Digging up deteriorated CMP drain pipe – cause of sinkhole in Photo 37.



Figure 39: Photo of rodent hole in embankment (Fischer, Tips and Tricks for Inspecting Dams and Canals n.d.).



Figure 40: Photo of corroded CMP outlet (U.S. Department of Transportation, FHWA 2010).



Figure 41: Photo of whirlpool in a Chouteau County dam (MT DNRC).

3.3 INTERIOR INSPECTION

Interior inspection of CMP conduits gives the best information regarding the condition of the conduit. Several items of concern should be noted during an interior inspection; these are discussed in further detail below. If it is possible for an inspector to enter the conduit, he “should use a measuring tape or pace off the location of all damaged or questionable areas within the conduit. Damage or questionable areas should be documented using still, digital, or video camera equipment” (FEMA 2005).

Difficulties of interior inspection

Crawling inside of a CMP can be a difficult task. “Generally, CMPs that are 36 inches or larger in diameter may be inspected by man-entry, if proper OSHA precautions are taken. Conduits with diameters smaller than 36 inches are generally inaccessible for man-entry and require specialized services” (FEMA 2005). Following are a few issues that should be considered prior to man-entry.

- **Dewatering of conduit**

The conduit must be, to a great degree, dewatered prior to man-entry. This may be difficult or impossible for a number of reasons: 1) lack of closure device, 2) need to drawdown reservoir, 3) ability of pipe to withstand pressures in dewatered condition.

- **Poor air quality**

This “may include lack of oxygen and the existence of hydrogen sulfide” (FEMA 2005).

- **Inaccessibility**

Many CMPs are simply too small for man-entry. If this is the case, other, more specialized, means of inspection may be considered. These are discussed in further detail below.

Things to look for:

- **Water ponding on invert of CMP**

The CMP was likely initially installed at a downhill grade from upstream to downstream. Ponding at the outlet may be evidence of settlement farther up the conduit. See Figure 42 below.

- **Joint separations and misalignment of CMP sections.** See Figure 43.

- **Metallic corrosion.** See Figure 44.

- **Damaged protective coatings.** See Figure 45.

- **Deformations of CMP circumference.** See Figure 46.

- **Leakage into or out of CMP.** See Figure 47.

- **Blockages at entrance to CMP**



Figure 42: Settlement in conduit causing ponding of water at invert (FEMA 2005).



Figure 43: Photo showing joint separations in CMP (U.S. Department of Transportation, FHWA 2010)



Figure 44: Photo showing corrosion of CMP (MT DNRC).



Figure 45: Photo showing polymer coating loss on CMP (U.S. Department of Transportation, FHWA 2010).



Figure 46: Photo showing deformed CMP in a Powell County dam (MT DNRC).

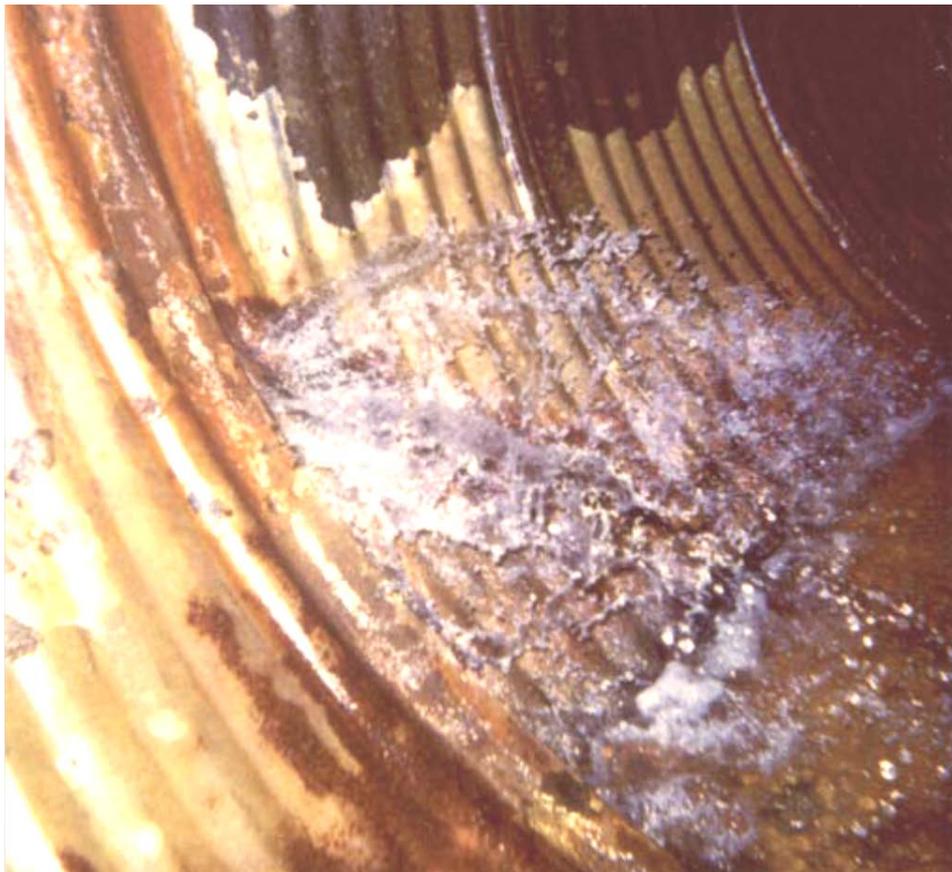


Figure 47: Photo of leaking into CMP conduit (FEMA 2005).

Specialized inspection

When man-entry of the culvert is not an option, other more specialized techniques must be used.

- **Closed circuit television (CCTV)**

CCTV and man-entry are the most common methods of conduit inspection.

While this method has yet to be used for rural Montana dams, costs are coming down as more businesses obtain the equipment. Dam owners may look in the Yellow Pages for companies who perform this sort of work. “A CCTV inspection consists of a video camera attached to a self-propelled transport vehicle (crawler)...Video images are transmitted from the camera to a television monitor, from which the operator can view the conditions within the conduit” (FEMA 2005).



Figure 48: A CCTV inspection camera-crawler entering a conduit (FEMA 2005).

Images of the interior of conduits that have been captured using CCTV are included in the following figures.



Figure 49: Photo taken by CCTV of deformation on interior of CMP conduit (U.S. Department of Transportation, FHWA 2010).



Figure 50: Photo taken by CCTV of seepage entering a CMP (FEMA 2005).

- **Dam Safety Program – Inspection Sled and Still Camera**

The MT DNRC Dam Safety Program has an inspection sled with a still camera that may be borrowed. The inspection sled works very well for smaller diameter pipes that do not allow for man-entry. One difficulty with interior inspection with the sled camera is often the voids are in between corrugations, and since the camera only takes straight on photos, these voids can be missed. Another difficulty is that corrosion usually occurs from the outside in – so a pipe can be severely deteriorated, but no holes may be visible from the inside.



Figure 51: Dam Safety Program Inspection Sled with Still Camera (MT DNRC)

SECTION 4 - REHABILITATION, REPAIR, OR REPLACEMENT

4.1 DECISION MAKING TO REHABILITATE, REPAIR, OR REPLACE

Once it has been determined that a CMP has a deficiency or the potential for a future problem, corrective measures must be considered. Numerous factors, which vary from site to site, will play in the decision making process to rehabilitate, repair, or replace the conduit. A few of these factors include: “(1) the type and extent of the problem, (2) the size and function of the pipe, and (3) the physical limitations of the site” (Kula, Zamensky and King 2000).

4.2 REHABILITATION AND REPAIR

Rehabilitation and repair will be discussed in conjunction because of their similarity when considering CMP. As technology has advanced, rehabilitation of pipes has become a popular means of avoiding the traditional remove and replace method. The two primary “trenchless technologies” used in the rehabilitation of pipes are sliplining and cured-in-place pipe (CIPP); each is discussed in further detail below.

Sliplining

Sliplining, in brief, is “where a smaller pipe is inserted into the existing pipe and grouted in place” (Van Aller 1996). This solution is used “when it is apparent that the existing CMP has limited design life remaining but is in adequate condition at the time of inspection. A successful slipline application will resolve ‘typical’ problems such as pipe corrosion, leaking joints and occasionally structural failure” (Kula, Zamensky and King 2000). However, sliplining will not resolve the problem if there is piping along the outside of the CMP.

- **Material Options**

The most common material used in sliplining is high density polyethylene (HDPE) due to its durability, watertightness, and cost effectiveness. Polyvinyl chloride (PVC) pipe has also been used, but has numerous disadvantages compared to HDPE. Steel pipe is also used in sliplining applications and works well for larger diameter pipes, which allow for man-entry and the welding of section joints. It is also best if the existing conduit is straight, without significant slope changes. Steel pipe slipliners can accommodate this if the diameter is large enough to allow for the insertion of fabricated pipe sections. Other proprietary products are available for sliplining and are best suited for non-pressurized, low-head embankment dams. Snap-Tite[®], for instance, utilizes a mechanical joint and

requires the use of a high SDR (thin-walled) pipe. The structural strength of the system, then becomes very dependent on the grout, which can be problematic if the grout doesn't completely fill all the voids.

Many different options are available for sliplining materials, but the discussion of this manual will focus only on HDPE. However, many of the advantages, disadvantages, and other considerations will apply to all material options.



Figure 52: Sliplining a Meagher County dam with HDPE pipe (MT DNRC)



Figure 53: Sliplining and grouting a Wheatland County dam CMP outlet pipe with a mechanically joined HDPE liner (MT DNRC).

-
- **Advantages**
 - Minimize excavation
 - Shorter construction time
 - Lower cost compared to other rehabilitation or replacement alternatives on higher-head dams
 - Resists corrosion
 - Lower friction loss due to smooth walls
 - Maintain reservoir level. This is possible if an upstream control on the conduit exists and the slipliner can be installed from the downstream end

 - **Disadvantages**
 - Sliplining is not appropriate where the existing conduit has deteriorated and the “surrounding embankment has been damaged by [piping]” (FEMA 2005). If the pipe is too deteriorated, slip lining can cause water to concentrate along the outside of the pipe causing progressive failure. Sliplining should not be used for pipes that have big holes.
 - Even with HDPE, sliplining is mostly limited to straight conduits, unless man-entry is feasible.
 - High coefficient of thermal expansion can cause movement of slipliner.
 - Requires specialized contractors to install slipliner and grout. Grout is difficult to install correctly to seal the entire annular space.
 - Loss of reservoir – it is typical to drain the reservoir to gain access to both the upstream and downstream ends of the conduit.
 - More expensive on lower-head dams compared to replacement alternatives.

 - **Considerations (Van Aller 1996)**
 - Seepage paths – “When an HDPE slipliner installation eliminates seepage into the conduit, the flow patterns within the surrounding embankment are changed and other undesirable seepage paths may develop...This must be addressed by installing a filter diaphragm or collar at the downstream end of the existing conduit” (FEMA 2005). Refer to pages 47 and following for a discussion of filter diaphragms.
 - Condition of existing pipe – capable of containing the new pipe and pumped grout.

-
- Hydraulic capacity of slipliner pipe – capable of conveying required flow volume with smaller diameter pipe.
 - Slipliner structural capacity – capable of carrying the required load assuming no support from the existing pipe. This is a very important consideration. Sliplining with HDPE does not work well where the existing pipe provides no structural support.
 - Slipliner joint type.
 - Installation method.
 - Thermal expansion and contraction – ensure that slipliner is long enough.
 - Grout mix – designed to flow through annular space without voids or air pockets – usually requires additives to ensure adequate flowability.



Figure 54: Photo of completed HDPE slipliner in CMP conduit in Wheatland County dam (MT DNRC).

Cured-in-place pipe (CIPP)

CIPP is also referred to as an “elastic sock.” CIPP liners “are best suited for existing conduits that are not severely damaged or deformed and have constant diameters and no sharp bends” (FEMA 2005). CIPP consists of a polyester needle-felt or glass fiber/felt reinforcement preimpregnated with polyester resin. The liner is typically pulled from one end of the conduit to the other. In order to cure the pipe, pressurized hot water (approximately 180 °F) is

pumped through the liner, and it takes the shape of the host pipe. After curing is complete, the ends may be trimmed.

- **Advantages**

- Minimize excavation.
- Shorter construction time.
- Resists corrosion.
- The need for grouting is eliminated.
- Lower friction loss due to smooth walls.

- **Disadvantages**

- High material and installation costs.
- CIPP is not suited for conduits with significant bends or changes in diameter.
- Requires specialized contractors.
- Loss of reservoir – it is typical to drain the reservoir to gain access to both the upstream and downstream ends of the conduit.

- **Considerations**

- Seepage paths – see the discussion of seepage paths for slipliner.
- Condition of existing pipe – check for any misalignment or deformation that would prevent the liner from being installed.
- Hydraulic capacity – capable of conveying required flow volume with smaller diameter pipe. Very little cross-sectional area is lost due to the thin gage of the liner.
- CIPP structural capacity – the CIPP liner will be designed based on the condition of the existing pipe, whether it is partially or fully deteriorated.
- Installation method.
- Joints are not typically used; CIPP is installed as one continuous length
- Thermal expansion and contraction – this not usually a significant concern with CIPP.



Figure 55: CIPP liner installation at Taylor Dam, Powell County, Montana (Fischer 2009).



Figure 56: CIPP installation at Upper Taylor Dam, Powell County, Montana (Fischer 2009).

Filter diaphragms

Filter diaphragms should be used in conjunction with both the sliplining and CIPP conduit rehabilitation methods. If another filter zone (e.g. chimney drain) is present and functioning within an existing dam, a filter diaphragm may not be necessary. A filter diaphragm consists of graded sand and/or gravel material and is installed around the conduit. The filter acts “both as a drain to carry off water and as a filter to intercept soil particles being transported by the water.” Filter zones “have become the accepted method of preventing failures caused by uncontrolled flow of water through the embankment” (FEMA 2005). Figure 57 and Figure 58 below show schematics of typical filter diaphragm installations.

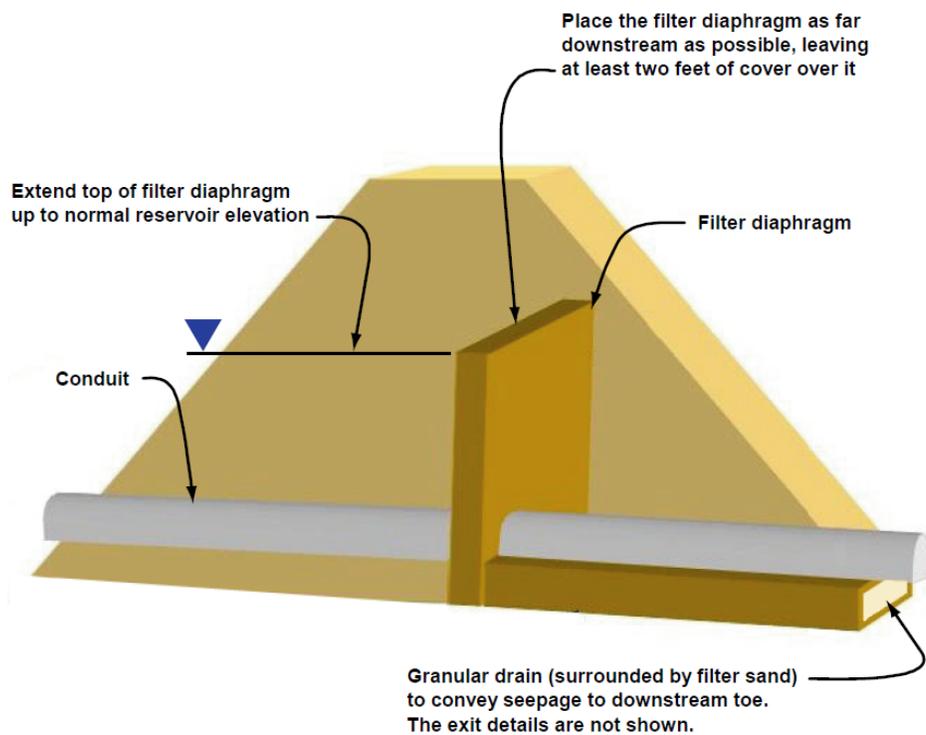


Figure 57: Profile view - typical configuration of filter diaphragm (FEMA 2005).

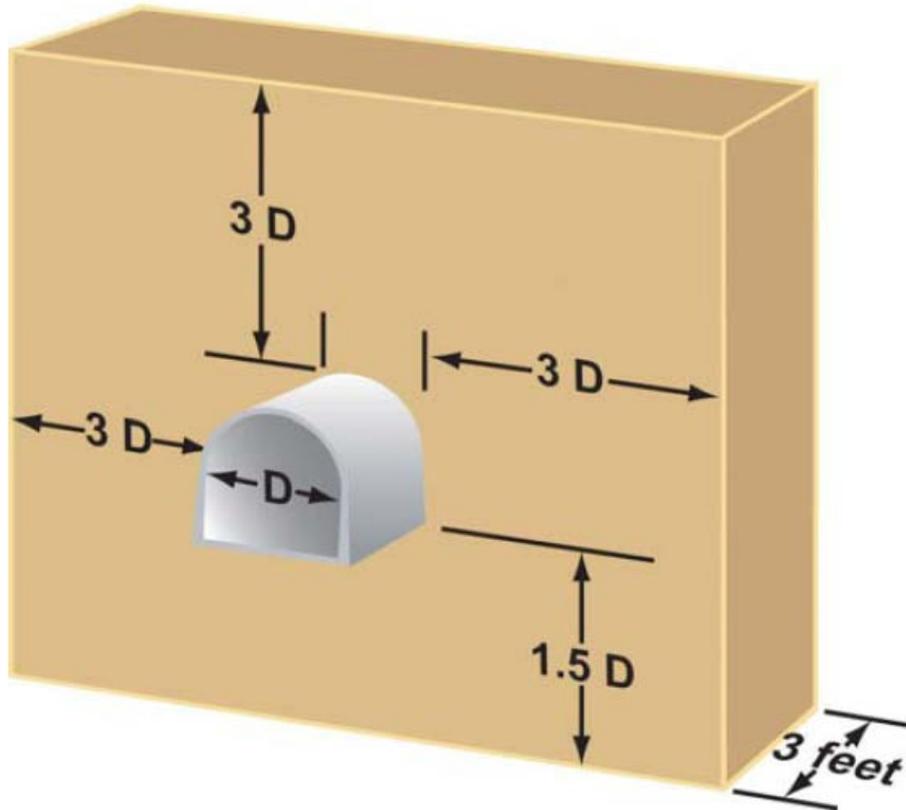


Figure 58: Typical configuration for a filter diaphragm (FEMA 2005).

4.3 REPLACEMENT

The process by which an existing conduit is removed and replaced generally consists of excavating down to the existing conduit, stockpiling the material, removing the existing conduit, and installing the new conduit. New entrance and terminal structures and a filter diaphragm may also be installed.

“Typically, construction costs for removal and replacement may be 5 to 10 times higher than for sliplining or CIPP renovation methods...However, if the embankment dam is small and the downstream impacts to users are acceptable; this method may be more advantageous than renovation...This is especially true of older low hazard embankment dams, where they may have been built without adequate engineering. Few designers will want to try and guess how the embankment dam was built. The safer and more efficient solution would be to remove and replace the conduit and possibly the entire dam” (FEMA 2005).

It is recommended that dams under 25 feet in height consider replacement as the primary option.

- **Advantages**

- The conduit and the foundation may be fully analyzed.
- The embankment along the conduit that may have been damaged by piping can be repaired.
- Seepage control measures, such as filter zones, may be installed.
- The design and efficiency of the dam may be improved to meet current operational standards.

- **Disadvantages**

- The installation of a cofferdam may be necessary if the reservoir cannot be fully drained. See Figure 59.
- High cost (in some cases) compared to rehabilitation options.

Construction considerations

- **Excavation of embankment**

Excavation will take place transverse to the embankment centerline; this inherently introduces a potential plane for hydraulic fracture. This should be taken into consideration during backfill and compaction of the embankment.

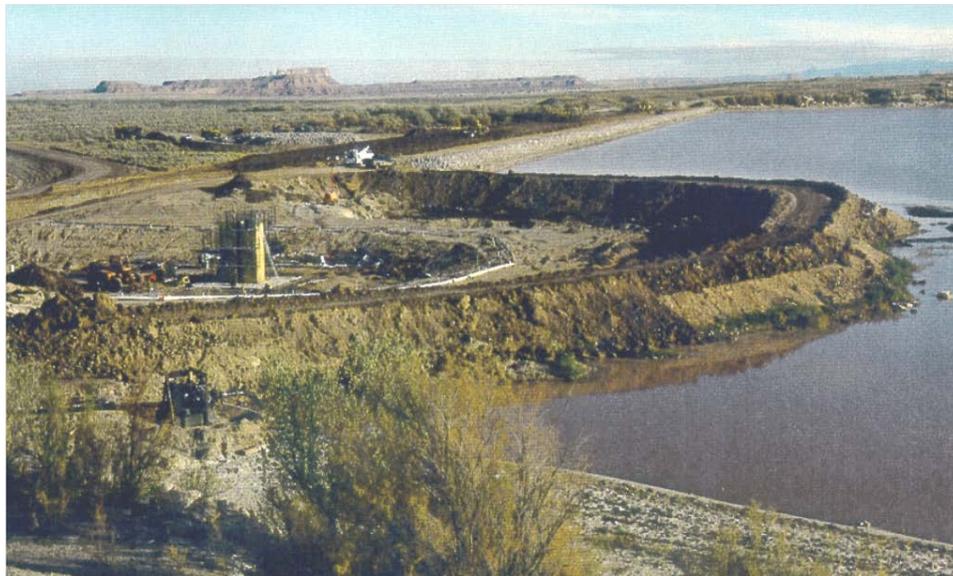


Figure 59: Photo of cofferdam around construction area for new outlet works (FEMA 2005).

- **Compaction**

Compaction of the embankment, especially around the conduit is crucial to the long term stability of the dam. This will help to prevent seepage paths from developing along the outside of the conduit and along the plane of excavation for the embankment.



Figure 60: Photo of nuclear density compaction testing on embankment for conduit replacement on a Powell County dam. Engineering students from Montana Tech look on. (MT DNRC)

Design and selection of new conduit:

The most common material used for conduits in embankment dams are: concrete, plastic, and metal. Each has its own advantages and disadvantages, and each requires specific design and construction considerations.

- **Reinforced cast-in-place concrete**

Reinforced cast-in-place concrete pipes have been used historically by major dam agencies and have proven to be very effective. “Properly designed and constructed reinforced cast-in-place pipe should have a service life of 100 years

of longer” (FEMA 2005). Cast-in-place conduits are typically only used on large dams due to their costliness.

- **Precast concrete**

Precast concrete used in conduits is “cast” at a plant, somewhere other than its final location. The sections used for conduits are usually circular. Precast concrete boxes are seldom used because it is difficult to achieve a watertight seal at the joints.

Advantages of precast concrete for conduits include:

- Quality control of precasting plant.
- Structural strength.
- Less emphasis needed on compaction for structural strength.
- Quick installation.
- Long design life

Disadvantages of reinforced cast-in-place concrete for conduits include:

- Reinforcement does not extend across joints.
- Short pipe lengths for shipping restrictions may mean numerous joints.
- Compaction is difficult under haunches of pipe -- a concrete support cradle is necessary.

- **HDPE**

HDPE pipe is commonly used in sliplining applications, but can also be used for a new conduit.

Advantages of HDPE for conduits include:

- Lightweight.
- Corrosion resistant.
- Smooth interior – low friction loss .
- Ability to fuse joints and make them watertight.

Disadvantages of HDPE for conduits include:

- High coefficient of thermal expansion – can cause movement of pipe.
- Compaction at haunches difficult unless encased in concrete.

-
- Requires proper compaction for structural integrity.
 - If dam is subject to State dam safety regulatory oversight, concrete encasement is required.
 - 50 year design life
 - **PVC**

PVC is not as commonly used in embankment dam applications as HDPE. This is primarily due to concerns with the watertightness of the joints. The joints on PVC are the bell and spigot type, which have the potential to leak as the dam settles. “Use of PVC...should only be considered for nonpressurized, low hazard dam applications” (FEMA 2005).
 - **Ductile Iron Pipe**

Ductile iron pipe is formed by introducing molten iron into a mold. It is able to deform more than cast-iron pipe and also has a greater tensile and compressive strength. The pipe must be lined for corrosion prevention.

Advantages of ductile iron pipe for conduits include:

- Tight manufacturing tolerances.
- Long service life if coatings are used.
- High compressive and tensile strength.
- Structural strength.
- Flanged joints provide watertightness.

Disadvantages of ductile iron pipe for conduits include:

- Heavy pipe makes handling difficult.
- Requires proper selection of linings and coatings or cathodic protection to prevent corrosion.
- Requires concrete encasement in high hazard embankment dams.

- **Steel pipe**

Steel pipe starts as plates, which are butt welded together and then rolled to the curvature of the pipe. The interior of the pipe is typically coated, while the exterior surface is left bare and is encased in concrete.

Advantages of steel pipe for conduits include:

-
- Tight manufacturing tolerances.
 - Long service life if coatings are used.
 - High compressive and tensile strength.
 - Welded joints provide watertightness.

Disadvantages of steel pipe for conduits include:

- High material costs.
- High installation cost due to welded joints.
- Requires proper selection of linings and coatings to prevent corrosion.
- Requires concrete encasement in high hazard embankment dams.

- **CMP**

CMP is produced from sheet steel with added corrugations for stiffness and strength. It is joined with coupling bands that are tightened against the pipe with bolts. “CMP has a service life of about 25 to 50 years. However, depending on reaction to certain soils and water conditions, there are cases where CMP has deteriorated in less than 7 years” (FEMA 2005). Utilizing the coatings described in Section 2.3 will extend the service life of CMP. The NRCS currently limits their use of CMP to low hazard embankment dams. The disadvantages and problems with CMP have been previously described.



Figure 61: Photo of reinforced cast-in-place conduit in a Jefferson County dam. Installed circa 1914 (MT DNRC).



Figure 62: Photo of precast concrete pipe being installed in a Powell County dam (MT DNRC).



Figure 63: Photo of HDPE pipe being installed in a Powell County dam (MT DNRC).



Figure 64: Photo of PVC pipe in a Colorado dam (Colorado Dam Safety).



Figure 65: Photo of ductile iron pipe, photo courtesy of Ductile Iron Pipe Research Association.



Figure 66: Photo of steel pipe to be installed in a Pondera County dam (MT DNRC).



Figure 67: Photo of polymer coated CMP used for riser in a Fergus County dam (MT DNRC).

Siphoning

A siphon may be used in the replacement of a conduit to partially drain a reservoir. Siphons are usually placed up and over the top of the embankment and are constructed of PVC, HDPE, or steel pipe. It should be ensured that the pipe is sufficiently rigid to handle the negative pressures that occur in the siphon. The outlet works in Keep Cool Dam in Meagher County, MT were recently replaced with a siphon system. See Figure 68 below.

Abandonment

In some situations, abandonment of the conduit may be deemed to be more technically and economically feasible than removing it. This is usually accomplished by grouting the conduit and leaving it in place. A filter diaphragm should be constructed if the conduit is abandoned to intercept any flow from defects along the conduit.

Another possible reason to abandon a culvert would if it were utilized as a diversion during the installation of a new conduit.



Figure 68: A siphon constructed at a Meagher County dam, used to replace the outlet works (MT DNRC).

SECTION 5 - OTHER CONSIDERATIONS

5.1 OBTAINING THE SERVICES OF A QUALIFIED PROFESSIONAL ENGINEER

Need for an engineer, Liability, and the Montana Dam Safety Act

The majority of embankment dams across the nation and in Montana are privately owned, and the responsibility for their proper operation and maintenance rests with the owner. The Montana legislature passed legislation in 1985 dealing specifically with dam safety, liability, and responsibility. The legislature understands that the construction of storage reservoirs is important for Montana, but acknowledges that the liability associated with owning a dam is an impediment. There are some key points in this act worth noting:

MCA 85-15-115 (2) states: “The legislature further finds that one impediment to the construction of new dams is the potential liability associated with dam construction and operation. The legislature understands the inherent risks to public safety associated with dam construction and operation but finds that compliance with the Montana Dam Safety Act reduces those risks to an acceptable level”.

Also note:

MCA 85-15-305 (2) states: “The owner of a dam or reservoir that has been permitted by the department in accordance with this chapter OR THAT WAS DESIGNED AND CONSTRUCTED UNDER THE SUPERVISION OF AN ENGINEER and properly maintained is, in the absence of negligence, not liable for damages to persons or property resulting from flows of water from failure of the dam or reservoir”

In other words, there is a degree of liability protection for dam owners that utilize licensed engineers.

Type of engineer needed

It is important to choose a registered professional engineer (P.E.) with a civil and geotechnical engineering background, who is competent and experienced in the field of dam safety. Following are several criteria to look for in a prospective engineer:

-
- A licensed professional engineer.
 - A minimum of 10 years of experience with embankment dam design, construction, and inspections.
 - A knowledge of the rules and regulations governing embankment dam design and construction in the State where the dam is located.
 - Specific experience in the problem areas, such as hydrology, hydraulics, structural, or geotechnical engineering.

Finding and choosing a qualified engineer

Your local DNRC Dam Safety engineer can provide you a list of engineers that specialize in dams. However they cannot recommend one engineering firm over another – it is up to you to call several engineers and ask the right questions. It is to your advantage to find an engineer that becomes familiar with your dam and will be a long term resource for you for many years to come. It is more beneficial to spend your hard earned dollars on an engineer preventing a dam failure than on attorneys in the aftermath of a dam failure.

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APPENDIX A – DNRC AND NRCS DAM CONTACTS

Montana DNRC – Dam Safety Program – Regional Engineering Offices

Bozeman Regional Office 2273 Boot Hill Court Suite 110 (406) 556-4501	Kalispell Regional Office 655 Timberwolf Parkway Suite 4 (406) 752-2713	Helena Regional Office 1424 Ninth Avenue (406) 444-9724
Havre Regional Office 210 Sixth Avenue (406) 265-5516	Lewistown Regional Office 613 NE Main, Suite E (406) 538-7459	Billings Regional Office 1371 Rintop Drive (406) 247-4423
Missoula Regional Office 2705 Spurgin Road Building C (406) 542-5885		

NRCS Field Offices in Montana

Baker Field Office (serves Little Beaver Conservation District) 141 South Fourth Street West P.O. Box 917 Baker, MT 59313-0917 Telephone: 406-778-2238 FAX: 406-778-2965	Big Sandy Field Office (serves Big Sandy Conservation District) 200 1st Street North P.O. Box 218 Big Sandy, MT 59520-0218 Telephone: 406-378-2298 FAX: 406-378-2479
Big Timber Field Office (serves Sweet Grass County Cons. District) 225 Big Timber Loop Road P.O. Box 749 Big Timber, MT 59011-0749 Telephone: 406-932-5160 FAX: 406-932-5285	Billings Field Office (serves Yellowstone Conservation District) Building A, Suite 4 1629 Avenue D Billings, MT 59102-3091 Telephone: 406-657-6135 FAX: 406-657-6277
Bozeman Field Office (serves Gallatin Conservation District) 3710 Fallon Street, Suite B Bozeman, MT 59718 Telephone: 406-522-4000 FAX: 406-522-4037	Bridger Plant Materials Center 98 South River Road Bridger, MT 59014-9514 Telephone: 406-662-3579 FAX: 406-662-3428

<p>Broadus Field Office (serves Powder River Conservation District) 114 North Lincoln Street P.O. Box 180 Broadus, MT 59317-0180 Telephone: 406-436-2321 FAX: 406-436-2809</p>	<p>Browning Field Office (serves Blackfeet Reservation) 640 All Chiefs Road P.O. Box 1169 Browning, MT 59417-1169 Telephone: 406-338-3153 FAX: 406-338-3529</p>
<p>Chester Field Office (serves Liberty County Conservation District) 18 Main Street P.O. Box 669 Chester, MT 59522-0669 Telephone: 406-759-5778 FAX: 406-759-5791</p>	<p>Chinook Field Office (serves Blaine County Conservation District) 230 Ohio Street P.O. Box 189 Chinook, MT 59523-0189 Telephone: 406-357-2320 FAX: 406-357-3597</p>
<p>Choteau Field Office (serves Teton Conservation District) 1102 Main Avenue NW Choteau, MT 59422-9624 Telephone: 406-466-5722 FAX: 406-466-3994</p>	<p>Circle Field Office (serves McCone Conservation District) 106 10th Street P.O. Box 276 Circle, MT 59215-0276 Telephone: 406-485-2744 FAX: 406-485-2621</p>
<p>Columbus Field Office (serves Stillwater Conservation District) 334 N. 9th Street Columbus, MT 59019 Telephone: 406-322-5359 FAX: 406-322-4639</p>	<p>Conrad Field Office (serves Pondera County Conservation District) 406 Main Street Conrad, MT 59425-2540 Telephone: 406-278-7611 FAX: 406-278-7997</p>
<p>Crow Agency Field Office 8645 South Weaver Drive Student Union Building Room 205 P.O. Box 699 Crow Agency, MT 59022 Telephone: 406-638-9102 FAX: 406-638-9101</p>	<p>Culbertson Field Office (serves Roosevelt County Cons. District) 508 6th Street East P.O. Box 517 Culbertson, MT 59218-0517 Telephone: 406-787-5232 FAX: 406-787-6132</p>
<p>Cut Bank Field Office (serves Glacier County Conservation District) 1 Third Street NE Cut Bank, MT 59427 Telephone: 406-873-4292 FAX: 406-873-3473</p>	<p>Deer Lodge Field Office (serves Deer Lodge Valley Cons. District and North Powell Cons. District) 1002 Hollenback Road, Suite C Deer Lodge, MT 59722-9513 Telephone: 406-846-1703 FAX: 406-846-3134</p>

<p>Dillon Field Office (serves Beaverhead Conservation District) 420 Barrett Street Dillon, MT 59725-3572 Telephone: 406-683-3800 FAX: 406-683-3840</p>	<p>Ekalaka Field Office (serves Carter County Conservation District) 308 Mormon Street P.O. Box 313 Ekalaka, MT 59324-0313 Telephone: 406-775-6355 FAX: 406-775-6671</p>
<p>Eureka Field Office (serves Lincoln Conservation District) 949 Highway 93 North Eureka, MT 59917-9550 Telephone: 406-296-7152 FAX: 406-296-7188</p>	<p>Forsyth Field Office (serves Rosebud Conservation District) 270 S. Prospect Street P.O. Box 1200 Forsyth, MT 59327-1200 Telephone: 406-346-7333 or 406-346-7501 FAX: 406-346-7501</p>
<p>Fort Belknap Field Office 158 Tribal Way, Suite D Harlem, MT 59526 Telephone: 406-353-8488 FAX: 406-353-2228</p>	<p>Fort Benton Field Office (serves Chouteau County Conservation District) 1210 25th Street P.O. Box 309 Fort Benton, MT 59442-0309 Telephone: 406-622-5627 FAX: 406-622-3728</p>
<p>Glasgow Field Office (serves Valley County Conservation District) 54062 U.S. Highway 2 West, Suite 2 Glasgow, MT 59230-2838 Telephone: 406-228-4321 FAX: 406-228-4359</p>	<p>Glendive Field Office (serves Dawson County Conservation District) 102 Fir Street Glendive, MT 59330-3197 Telephone: 406-377-5566 FAX: 406-377-4607</p>
<p>Great Falls Field Office (serves Cascade County Conservation District) 12 3rd Street NW Great Falls, MT 59404-1991 Telephone: 406-727-7580 FAX: 406-761-8089</p>	<p>Hamilton Field Office (serves Bitterroot Conservation District) 1709 N. First Street Hamilton, MT 59840-3112 Telephone: 406-363-5010 FAX: 406-363-5011</p>
<p>Hardin Field Office (serves Big Horn Conservation District) 724 Third St. West Hardin, MT 59034-1604 Telephone: 406-665-3442 FAX: 406-665-1486</p>	<p>Harlowton Field Office (serves Upper Musselshell Cons. District) 809 Second Avenue NW P.O. Box 4918 Harlowton, MT 59036-0918 Telephone: 406-632-5534 FAX: 406-632-4624</p>

<p>Havre Field Office (serves Hill County Conservation District) 206 25th Avenue West, Suite 1 Havre, MT 59501-3418 Telephone: 406-265-6792 FAX: 406-265-1418</p>	<p>Helena Field Office (serves Lewis and Clark Conservation District) 790 Colleen Street Helena, MT 59601-9713 Telephone: 406-449-5000 FAX: 406-449-5039</p>
<p>Hysham Field Office (serves Treasure County Conservation District) 211 Elliott Avenue P.O. Box 187 Hysham, MT 59038-0187 Telephone: 406-342-5510 FAX: 406-342-5524</p>	<p>Joliet Field Office (serves Carbon Conservation District) 606 W. Front Street P.O. Box 510 Joliet, MT 59041-0229 Telephone: 406-962-3641 FAX: 406-962-3995</p>
<p>Jordan Field Office (serves Garfield County Conservation District) 307 Main Street P.O. Box 369 Jordan, MT 59337-0369 Telephone: 406-557-2232 FAX: 406-557-6191</p>	<p>Kalispell Field Office (serves Flathead Conservation District) 133 Interstate Lane Kalispell, MT 59901-7921 Telephone: 406-752-4242 FAX: 406-752-4879</p>
<p>Lame Deer Field Office East Boundary Dr. P.O. Box 330 Lame Deer, MT 59043-0330 Telephone: 406-477-6494 FAX: 406-477-8431</p>	<p>Lewistown Field Office (serves Fergus Conservation District) 211 McKinley Street, Suite 3 Lewistown, MT 59457-2020 Telephone: 406-538-7401 FAX: 406-538-9353</p>
<p>Livingston Field Office (serves Park Conservation District) 5242 Highway 89 South Livingston, MT 59047-9611 Telephone: 406-222-2899 FAX: 406-222-8538</p>	<p>Malta Field Office (serves Phillips Conservation District) 1120 U.S. Highway 191 South, Suite 2 Malta, MT 59538 Telephone: 406-654-1334 FAX: 406-654-1691</p>
<p>Miles City Field Office (serves North Custer Conservation District) 3120 Valley Drive East Miles City, MT 59301-5500 Telephone: 406-232-7905 FAX: 406-232-3965</p>	<p>Missoula Field Office (serves Mineral County and Missoula Conservation Districts) 3550 Mullan Road, Suite 106 Missoula, MT 59808-5125 Telephone: 406-829-3395 FAX: 406-829-3455</p>

<p>Pablo Field Office Tribal Lands Department 42487 Complex Boulevard Pablo, MT 59855-0871 Telephone: 406-675-1245 FAX: 406-675-2804</p>	<p>Philipsburg Field Office (serves Granite Conservation District) 105 S. Holland P.O. Box 926 Philipsburg, MT 59858-0926 Telephone: 406-859-3291 FAX: 406-859-3607</p>
<p>Plains Field Office (serves Eastern Sanders County and Green Mountain Conservation Districts) 7487 Montana Highway 200 Plains, MT 59859 Telephone: 406-826-3701 FAX: 406-826-3273</p>	<p>Plentywood Field Office (serves Sheridan County Conservation District) 119 N. Jackson Plentywood, MT 59254-1599 Telephone: 406-765-1801 FAX: 406-765-1551</p>
<p>Poplar Field Office 500 Medicine Bear Road Box 1027 Poplar, MT 59255-1027 Telephone: 406-768-3566 FAX: 406-768-3373</p>	<p>Rocky Boy Field Office (serves Chippewa Cree Tribe) P.O. Box 3008 Box Elder, MT 59521 Telephone: 406-395-4066 FAX: 406-395-4382</p>
<p>Ronan Field Office (serves Lake County Conservation District) 64352 Highway 93 Ronan, MT 59864-8738 Telephone: 406-676-2841 FAX: 406-676-2810</p>	<p>Roundup Field Office (serves Lower Musselshell Conservation District) 109 Railroad Avenue East Roundup, MT 59072-2930 Telephone: 406-323-2103 FAX: 406-323-1548</p>
<p>Scobey Field Office (serves Daniels County Conservation District) 131B Highway 5 East P.O. Box 605 Scobey, MT 59263-0605 Telephone: 406-487-5366 FAX: 406-487-2276</p>	<p>Shelby Field Office (serves Toole County Conservation District) 1125 Oilfield Avenue P.O. Box 919 Shelby, MT 59474-0919 Telephone: 406-434-5234 FAX: 406-434-2718</p>
<p>Sheridan Field Office (serves Ruby Valley Conservation District) 402 South Main Sheridan, MT 59749 Telephone: 406-842-5741 FAX: 406-842-5914</p>	<p>Sidney Field Office (serves Richland County Conservation District) 2745 West Holly Street Sidney, MT 59270-4299 Telephone: 406-433-2103 FAX: 406-433-7351</p>

<p>Stanford Field Office (serves Judith Basin Conservation District) 121 Central Avenue Stanford, MT 59479-0386 Telephone: 406-566-2311 FAX: 406-566-2727</p>	<p>Terry Field Office (serves Prairie County Conservation District) 410 East Spring St. P.O. Box 217 Terry, MT 59349-0217 Telephone: 406-635-5381 FAX: 406-635-4210</p>
<p>Townsend Field Office (serves Broadwater Conservation District) 415 South Front Street Townsend, MT 59644-0147 Telephone: 406-266-3146 FAX: 406-266-5429</p>	<p>Whitehall Field Office (serves Jefferson Valley Conservation District, Madison Conservation District, and Mile High Conservation District) 3 Whitetail Road Whitehall, MT 59759 Telephone: 406-287-3215 FAX: 406-287-3205</p>
<p>White Sulphur Springs Field Office (serves Meagher County Conservation District) P.O. Box 589 4147 Highway 12 White Sulphur Springs, MT 59645-9509 Telephone: 406-547-3633 FAX: 406-547-3912</p>	<p>Wibaux Field Office (serves Wibaux Conservation District) 502 2nd Avenue NW Wibaux, MT 59353-9040 Telephone: 406-796-2211 FAX: 406-796-9942</p>
<p>Winnett Field Office (serves Petroleum County Conservation District) 813 North Broadway P.O. Box 118 Winnett, MT 59087-0118 Telephone: 406-429-6646 FAX: 406-429-2015</p>	

APPENDIX B - COMMON ABBREVIATIONS

AASHTO, American Association of State Highway and Transportation Officials
AISI, American Iron and Steel Institute
ASCE, American Society of Civil Engineers
ASDSO, Association of State Dam Safety Officials
CAT, computerized axial tomography
CCTV, closed circuit television
CD-ROM, compact disc—read-only memory
CIPP, cured-in-place pipe
CMP, corrugated metal pipe
CPS, cathodic protection system
CSP, corrugated steel pipe
DVD, digital versatile disc
EAP, Emergency Action Plan
FEMA, Federal Emergency Management Agency
FERC, Federal Energy Regulatory Commission
FHWA, Federal Highway Administration
GPR, ground penetrating radar
GPS, global positioning system
HDD, horizontal directional drilling
HDPE, high density polyethylene
ICODS, Interagency Committee on Dam Safety
ICOLD, International Commission on Large Dams
JHA, job hazard analysis
LL, liquid limit
MT DNRC, Montana Department of Natural Resources and Conservation
NDSRB, National Dam Safety Review Board
NDT, nondestructive testing
NRCS, Natural Resources Conservation Service
O&M, operation and maintenance
OSHA, Occupational Safety and Health Administration
P.E., professional engineer
PE, polyethylene
PDF, portable document format
PI, plasticity index
PPI, Plastic Pipe Institute
PVC, polyvinyl chloride
RCP, reinforced concrete pipe
Reclamation, Bureau of Reclamation
ROV, remotely operated vehicle
SCS, Soil Conservation Service
SDR, standardized dimension ratio
TADS, Training Aids for Dam Safety
USACE, U.S. Army Corps of Engineers
USDA, United States Department of Agriculture
UV, ultraviolet