D-1440

United States Department of the Interior

BUREAU OF RECLAMATION
PO Box 25007
Denver, Colorado 80225-0007

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:

D-8312
PRJ-13.00

AUG 26 2005

MEMORANDUM

To: Regional Director
Attention: PN-1000, MP-100, LC-1000, UC-100, GP-1000

From: Bruce Muller
Chief, Dam Safety Office

Subject: Interim Guidelines for Embankment Drain Inspections, Evaluation and Follow-Up Activities

Attached for your use are guidelines for embankment drain inspections, evaluation and follow up activities prepared at the request of the Dam Safety Office (DSO). These guidelines are intended for use throughout Reclamation and will be revised as needed after a period of one year's use.

The DSO requested the development of these guidelines due to concerns about the consistency of recommendations, the risks involved in carrying out the recommendations, and the potential costs of making all toe drains accessible. This guideline directly addresses the issues and findings associated with toe drain inspection reports as presented in the Dam Safety Program -Independent Review Panel Report – Sixth Annual Review dated February 2004.

A draft of this guideline was widely circulated and reviewed in the regional and area offices along with Technical Service Center (TSC) at the request of the DSO. The guideline has been finalized with input received in early 2005 from this review. An effort was made to incorporate to the degree possible the wide variety of comments received. Major changes to the document from this review included:

- Revisions to responsibilities for inspection and inspection reports. Any entity across Reclamation can perform the inspections if they have the capability or access to capability.

- The Principal Engineer, using SEED funding, will promptly peer review the inspection report and any findings generated by those who have assumed responsibility for performing the inspections.

- The Principal Engineer, using SEED funding associated with the Comprehensive Facility Review (CFR) process, will evaluate the embankment drain system using all available information including the inspection results.

- Any risk based dam safety issues and follow up activities identified by inspections, and peer reviewed by the Principal Engineer, will be initially addressed using SEED funding. Modifications, should they be determined necessary, will be funded using SOD or O&M funding, as appropriate.

Inspection of embankment (toe) drains has varied significantly across Reclamation. The document describes the need and value of completing an initial inspection of embankment drains. Although not specifically cited, the initial inspection of toe drains, being similar to the examinations of other normally inaccessible features listed and described in the Reclamation Manual, Directive and Standards FAC 01-07, should be treated in a like manner and funded accordingly. Reclamation regional and area offices should begin formulating a strategy for performing and documenting closed circuit television (CCTV) inspections of these embankment drains when associated with any of our significant and high hazard facilities. The results of the inspections will be evaluated in the proceeding CFR.

CCTV inspection of drain pipes in embankments (i.e., toe drains) is an important extension of an examination of a dam and as an enhancement of visual monitoring. Inspection of drains is important because internal erosion (piping) associated with seepage is an important failure mode at nearly every embankment dam and drains, by their nature, are likely places to detect changing conditions.

The guiding principle in the document for all decisions related to existing drains is to "DO NO HARM". Thus, if a particular embankment drain is judged to be non-critical to the safe performance of a dam, has none to minor clear flows, is made of weak materials and appears to have a slight amount of bio-fouling, cleaning would not be recommended due to the risk of damaging the pipe and the surrounds at little chance for improvement to the safety of the dam. The guidelines recognize that each embankment (toe) drain is somewhat unique as their function and importance to the safety of a dam are dependent upon their location; design of the drain; foundation conditions, including geology; performance history; as well as how robustly other design features were incorporated into the embankment to address the seepage related failure modes. Thus, the guidance recommends that judgments made about each embankment drain system consider all of these factors.

An initial drain inspection is envisioned to improve Reclamation's ability to manage the diverse risks associated with the potential for an internal erosion failure in such a large inventory of embankment dams. The inspections should also improve risk analyses by supplying more in depth information about the performance and structural integrity of drain systems. An inspection may also improve the agency's response to a developing failure mode by providing upfront information about the system most likely to reveal a changing condition.

These guidelines for embankment drain inspections, evaluations and follow-up activities are intended for use by operations and maintenance personnel, dam safety personnel, designers, and others who are involved with the inspection of embankment dams containing drainage systems at Reclamation dams. The team who prepared the guidelines consisted of members from a regional office, an area office, and the Technical Service Center. An electronic version of the guidelines will be provided in portable document format (pdf) on Reclamation's intranet site at intra.usbr.gov/~tcg/techdocs. For additional copies of the guidelines, or if you have questions, please, call Dave Mayer (D-1440), at 303-445-2989 or Chuck Redlinger (D-8312), at 303-445-2768.

Attachments

cc: Chief Dam Safety Office, Denver CO
Attention: D-1440
(10 attachments)

Dam Safety Officer, D-5000 (Vacant)
(1 attachment)

Regional Director, Boise ID
Attention: PN-3200, PN-3250
(3 attachments to each)

Regional Director, Sacramento CA
Attention: MP-400, MP-431
(3 attachments to each)

Regional Director, Boulder City NV
Attention: BCOO-4800, BCOO-4840
(3 attachments to each)

Regional Director, Salt Lake City UT
Attention: UC-250
(6 attachments)

Regional Director, Billings MT
Attention: GP-2400
(6 attachments)

Manager, Boise ID, Attention: SRA-1000
Manager, Grand Coulee WA, Attention: GCP-1000
Manager, Yakima WA, Attention: UCA-1000
Manager, Portland, OR, Attention: LCA-1000
Manager, Klamath Falls OR, Attention: KO-100
Manager, Carson City NV, Attention: LO-100
Manager, Shasta Lake CA, Attention: NC-100
Manager, Folsom, CA, Attention: CC-100
Manager, Fresno CA, Attention: SCC-100
Manager, Sacramento CA, Attention: CVO-100
Manager, Phoenix AZ, Attention: PXAO-1000
Manager, Boulder City NV, Attention: LCD-1000
Manager, Temecula CA, Attention: SCAO-1000
Manager, Boulder City NV, Attention: BCOO-1000
Manager, Yuma AZ, Attention: YAO-1000
Manager, Albuquerque NM, Attention: ALB-100
Manager, Farmington, NM, Attention: FCO-100
Manager, Durango, CO, Attention: ALP-100
Manager, Salt Lake City, UT, Attention: UC-600
Manager, Provo UT, Attention: PRO-100
Manager, Grand Junction CO, Attention: WCG-CDeAngelis
Manager, Bismarck ND, Attention: DK-100
Manager, Loveland CO, Attention: EC-1000
Manager, Billings MT, Attention: MT-100
Manager, Grand Island NE, Attention: NK-100
Manager, Austin TX, Attention: TX-Walkoviak
Manager, Mills WY, Attention: WY-1000

Director, Technical Service Center,
Attention: D-8011 (Lewis), D-8100 (Pimley), D-8200 (Karsell), D-8300 (Hensley), D-8400 (Boyle), D-8500 (Pierce)
Director, Office of Program and Policy Services,
Attention: D-5700 (Krause)
(w/3 attachments to each)

RECLAMATION
Managing Water in the West

Guidelines for Embankment Drain Inspections, Evaluation, and Follow-Up Activities

U.S. Department of the Interior
Bureau of Reclamation

July 2005

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Guidelines for Embankment Drain Inspections, Evaluation, and Follow-Up Activities

U.S. Department of the Interior
Bureau of Reclamation
Dam Safety Office
Denver, Colorado

July 2005

Contents

Statement of Goals and Objective

This document provides guidance related to the inspection and evaluation of embankment drains and the resulting recommendations for actions, such as maintenance or repair, within a risk framework. The term "embankment drain" is used in these guidelines to describe all drain pipes in embankment dams including toe drains and other drains located well within the body of the dam. Spillway and foundation drains are not addressed specifically but might require similar inspection, maintenance and repair. Relief wells are also not addressed but require a similar amount of inspection and typically require as much or more maintenance. More general guidance is provided in *Drainage for Dams and Associated Structures (2004) [1]*, which is a manual with the primary purpose of providing information that can be used to establish an effective drain maintenance program for any type of dam or drainage system.

Section I of the Guidelines provides a general discussion of embankment drains. Section II includes a template for the inspection, inspection reporting, and evaluation of embankment drains. It also includes a discussion of appropriate funding mechanisms for these activities. Section III provides a list of technical considerations for use by the Principal Engineer when reviewing results of the embankment drain inspection and considering the need for additional action. Section IV summarizes an array of alternatives for future actions relative to the embankment drains. Finally, the appendices provide a variety of information related to drain design and construction practices, as well as case histories related to drain inspections.

The guiding principal for all actions and decisions related to an existing embankment drain is "DO NO HARM."

I. Introduction

A. General

1. Why do we have embankment drains? The use and design intent of embankment drains has varied over the years. As discussed in the first edition of *Design of Small Dams* (1960), embankment drains were typically installed along the downstream toe of an embankment dam in conjunction with a horizontal drainage blanket [2]. The purpose of the drains was to collect seepage discharging from the horizontal drainage blanket and convey it to an outfall pipe that discharges into the spillway or outlet works stilling basin or into an open channel below the dam. Drains are also used on impervious foundations to ensure that any seepage that may come through the foundation or embankment is collected and that the groundwater is kept sufficiently below the surface to avoid unsightly boggy areas below the dam.

Pipes, rather than "French" drains, were typically used to ensure adequate capacity to carry seepage flow. The use of drain pipes in embankment dams, including Reclamation's inventory, has varied more than explained by this general statement, as some dams had drains located below the crest and even under the core. In addition, many drains were installed after original construction because of the observation of uncontrolled seepage. Drain pipes were also commonly used in "drainage trenches" excavated into pervious foundations overlain by impervious layers where the layer was thin enough to be penetrated by a trench. The term "embankment drain" is used in these guidelines to describe all of these types of drains. This guideline focuses on those embankment drains that contain a drain pipe of some kind that collects and conveys the seepage collected by the drain as these are drains that can be inspected and evaluated. The drain pipes are typically perforated or constructed with "open joints" in areas of anticipated seepage to allow for the collection of seepage and non-perforated pipe is typical in areas where only conveyance of the seepage is needed.

2. Problems specific to embankment drains Drain pipes may have had a key role in incidents and possibly the failure of dams in which the design of the dam relied on drains to control seepage but the drains were not properly designed or constructed for this function. The following is a summary of the problems associated with embankment drains and associated drain pipes:

- Envelope materials not meeting filter criteria allowing transport of soil particles directly into drain pipes

- Poor monitoring and maintenance of embankment drains reducing chances of detecting changing conditions. Many times the existing configuration of a drain pipe does not allow for good monitoring and maintenance.

- Sinkholes forming over broken or poorly constructed drain pipes (Clark Canyon Dam)

- Construction damage varying from minor, such as wood lath being driven through a plastic pipe, to severe, where construction equipment breaches the pipe. Some closed circuit television (CCTV)inspections, such as at Davis Creek and San Justo Dams, have revealed such damage, which likely occurred during construction.

- Plugging of perforations in the drain pipe occurring for reasons ranging from biofouling to soil particles being(from the filter) jammed into round pipe perforations by seepage forces

- Deterioration or damage to pipes from corrosion or freeze-thaw, depending on the type of drain pipe used

- Access problems, as manholes are rare in designs prior to the 1980's

- Settlement causing sags in embankment drain alignments resulting in boggy areas downstream of the dam

- Outfalls of drains have not been maintained and as a result have been covered up and not monitored or observed

- No "as built drawings" showing locations of drains or outfalls

- Roots blocking drain pipes and/or perforations

- Animal activity resulting in blocked drain pipes

The more serious of these problems have led to incidents that have damaged embankments, such as the formation of sinkholes, or have required construction of additional embankment drains to replace damaged or poorly performing drains. In many cases, the monitoring of embankment drains has indicated more serious problems that have led to incidents and even failure. The authors are not aware of a case where an embankment drain was the root cause of an embankment failure. However, in many cases, the development of a problem with an embankment or poor performance of an embankment drain is observed during monitoring, and remediation is done to prevent further development of a failure mode. In many designs, the embankment drain is a major feature in protecting against a critical failure mode, such as internal erosion through the foundation. Poor performance of the embankment drain may increase the likelihood of this failure mode. The performance of many embankment dams has also been improved by the presence of an effective drainage system.

3. Features of a good drainage system Key features of a good drainage system include:

- All materials and features are designed according to proven filter criteria.

- Drain systems have ample flow capacity.

- Adequate access is provided to the entire drain system to allow for inspection and maintenance.

- The system can be well monitored for seepage quantities and material transport.

A modern embankment dam design (designed after about 1976) typically is sufficiently robust to ensure adequate protection against seepage-related failure modes without relying solely on an embankment drain and its associated drain pipe. If an embankment drain or drain pipe is used in a modern design, it typically is used to collect and convey water from an internal filter/drain system or from a particular area of concern in the foundation, such as a natural spring, allowing observation and measurement of flows. Modifications to existing embankment dams have included embankment drains and associated drain pipes which are designed as the primary defense against a seepage-related failure mode, especially where foundation seepage is of concern. For a more complete list of salient features of a good embankment drain system, see appendix A.

B. Summary of Case Histories (Findings from Incidents and Recent CCTV Embankment Drain Inspections)

Many embankment dams have had incidents associated with drain systems, often referred to as "toe drains," regardless of their location in the dam or foundation. These incidents have ranged from non-harmful damage or deformations that occurred during construction to breach of a filter that resulted in internal erosion of foundation materials into the drain pipe. A summary list of some incidents is included in appendix B.

Past performance, visual inspections, and CCTV inspections have revealed that clay tile pipes with open joints were many times not constructed to the tolerances needed to prevent movement of surrounding soils. In addition, they have experienced joint offset and separation from improper installation, backfill loadings, or foundation conditions. The entry of sediments, gravels, and rocks into these embankment drain systems has resulted in obstructions for inspection, as well as plugging of the drain pipe.

Most corrugated metal pipes (CMP) have experienced deterioration ranging from minor to extensive, depending on age, the chemical and physical properties of the soils and water, and the pipes' exposure to the environment. Interior surface coatings appear to have been somewhat effective in extending the life of CMP pipes; however, most have experienced some loss of coating as a result of delamination.

In a significant number of instances, shape deformation and failure related to stress cracking have been observed in high density polyethylene (HDPE) pipe. Other failures could be the result of isolated point loads related to construction activities, such as equipment crossings or poor compaction of the surrounding backfill.

Bio-fouling, mineral incrustations, and root intrusion have frequently been observed plugging pipe perforations and slots, affecting their long term performance. CCTV inspection after the cleaning of pipes using jet washing has shown that the bio-fouling and mineral incrustation are generally removed from the pipes' interior surface. However, a determination of the extent of cleaning of the surrounding envelope materials is generally not possible. After cleaning, some increase in the discharge from these pipes is typically observed. It is likely that bio-fouling will return over time, which is typical of most drain installations.

For a summary of findings from CCTV inspections, see appendix D.

II. Inspection, Evaluation, and Reporting Process

All high and significant hazard embankment dams with embankment drain systems that contain a drain pipe should have an initial CCTV drain inspection to determine and document the condition of the parts of the drain pipe that are accessible. The initial inspection establishes a baseline from which future inspections can be compared. Inspection of drain pipes (i.e., toe drains) is viewed as prudent to the overall assessment of an embankment dam, an important extension of a typical inspection, and an enhancement of visual monitoring. Inspection of embankment drains is important, because internal erosion associated with seepage is a critical failure mode, and drains, by their nature, are likely places to detect changing conditions that could indicate the initiation of a failure mode.

An evaluation of each drainage system should be completed using these guidelines during the Comprehensive Facility Review (CFR) process. This activity should be addressed similarly to a feature covered under "D. Examination of Normally Inaccessible Features" in Reclamation Directive FAC 01-07, *Review/Examination Program for High- and Significant- Hazard Dams* [3]. Table 1 lists the steps recommended for the inspection, evaluation and reporting processes. Embankment drains that have already been inspected using CCTV should be evaluated using these guidelines starting with step 3 as defined in table 1.

Table 1.—Summary of schedule and budget for preparing the Embankment Drain Report of Findings

Steps and activity	Responsible Staff	Staff day estimate	Timeframe
A. Funding source: area office EES* budget (Non-reimbursible)			
1. CCTV inspection	Inspection specialist	Varies	If needed, preferably done in the year prior to the CFR exam.
2. Inspection report	Inspection specialist (Peer Review a duty of the Principal Engineer and funded by SEED)	Varies	Within 60 days of the inspection
B. Funding source: CFR budget (SEED)			
3. Report of findings a. Evaluation, review and draft ROF*	a. Principal engineer	In CFR budget (5 staff days on average)	a. Within 60 days of the inspection report
b. Peer review	b. Peer reviewer		b. Within 75 days of the inspection report
c. Peer-reviewed ROF for use in CFR	c. Principal engineer		c. Within 90 days of the inspection report and before the CFR initial meeting
4. ROF used as input to CFR. Recommendations, if any, made in CFR Report	Senior Engineer	In CFR budget	On CFR schedule
5. CFR DSAT includes discussion of the drain evaluation	Senior engineer	In CFR budget	On CFR schedule
6. Finalize CFR	Senior engineer	In CFR budget	2 weeks after DSAT meeting
C. Funding source: various (construction authorization, O&M*, SEED*, ISCA*, etc.)			
7. Future actions and/or follow-up activities (if needed)	Principal engineer, region, and area office, as appropriate	Varies	Varies

* Examination of Existing Structures (EES); report of findings (ROF); Dam Safety Advisory Team (DSAT); operation and maintenance (O&M); safety evaluation of existing dams (SEED); Initiate SOD Corrective Action (ISCA); Safety of Dams (SOD)

A. Inspection and Documentation

1. Description and scope of work activities included in the initial inspection and documentation The initial CCTV inspection procedure should include accessing as much of the embankment drain system as possible from existing entry points. For the initial inspection, no heroic attempt will be made to access inaccessible portions of the drain. Unwatering, such as what is done for stilling basins, should be considered where feasible. Generally, embankment drain inspection activities should be considered a normal operation and maintenance practice for the facility and should be covered by a Categorical Exclusion Checklist for National Environmental Policy Act (NEPA) purposes. However, special circumstances may warrant additional NEPA review prior to the inspection. Where applicable, consultation with an inspection specialist is recommended to ensure that inspection equipment capabilities are met (i.e., the equipment fits into and can access the pipe dimensions).

If an inspection reveals a critical condition, such as soil material are actively being carried into the drain pipe through a break or open joint, it should be reported immediately to the Area Office, Regional Office, Dam Safety Office (DSO) and the principal engineer for a decision.

At a minimum, the inspection reports should include the following items:

- Background information and a description of the dam and embankment drain system
- Description of the CCTV equipment used
- Description of how the CCTV inspection was conducted
- Summary of observed conditions
- Conclusions and considerations for future actions
- Color photographs taken from the videotaped inspection showing conditions, defects, etc.
- Drawings showing the limits of the CCTV inspection
- Detailed log of the videotaped inspection (minute vs footage)
- Color copies of the inspection videotapes

Typically, inspection reports will be prepared within 60 days of the completion of the field inspection. The inspection report will be peer reviewed by the Principal

Engineer as part of their care taker duties. The Principal Engineer will confirm in this review that there is not a need for expedited actions. As such, this peer review will be funded by SEED under the Principal Engineer's account. Each inspection report may include a list of considerations for future work for the principal engineer to evaluate. These considerations **will not** be in the SOD or O&M format (i.e., 200X-SOD-X). A summary of this inspection report will be included in the *Examination Report* section of the CFR similarly to other examinations of normally inaccessible features.

The requirements for CCTV inspection equipment can vary greatly, depending on the scope of the embankment drain inspection. No CCTV inspection equipment exists that is fully adaptable for all conditions, and a variety of crawler configurations and cameras may be required. Any company or contractor selected to perform a CCTV inspection should be very experienced and have a wide range of available equipment for differing site conditions. Most contractors only have experience with sewer applications and virtually no experience with the inspection of embankment drains within dams. Inexperienced contractors typically do not have the knowledge of defects or conditions that are dam safety related. The scope of the inspection and all products to be delivered by the contractor must be completely defined in the contract documents. Also, qualified Reclamation staff must be present while the contractor performs the entire CCTV inspection. As an alternative to procuring a contractor, the Technical Service Center (TSC) maintains a CCTV inspection program and can provide inspection services, including technical evaluation and preparation of the Report of Findings. Arrangements for CCTV inspection can be made through Chuck Cooper, Waterways and Concrete Dams (Bureau of Reclamation, Technical Service Center, D-8130, Denver, CO 80225, 303-445-3262).

2. Estimated cost and funding source The TSC's cost for CCTV inspection have typically ranged from about $3,000 to $5,000 in 2004 for a moderate sized embankment drain system. When multiple embankment drain inspections are performed at a number of nearby dams, the average cost per inspection is typically less. Additional costs associated with Area Office labor are not included in these estimates. Very large facilities with extensive embankment drain systems will have higher costs due to the complexities involved. Costs are obviously an important consideration to Area and Regional Offices, and it is understood that initial inspection of Reclamation facilities may occur over several years. Consideration should be made to scheduling several nearby facilities as a cost savings measure. A preliminary inspection by the Area Office using an underwater camera mounted on a push pole to determine the accessibility of the embankment drains could be performed in advance of a CCTV inspection. If the embankment drains are plugged or otherwise inaccessible to the CCTV equipment, this should be documented and could serve as the initial inspection. However, the condition of the outfall pipe is not always indicative of the entire embankment drain systems. Outfall pipes often experience much more sedimentation and bio-fouling due to their lack of positive drainage and the tendency for water to back up into the pipe due to tailwater inundating the outlet area.

As noted above, inspection of embankment drains is consistent with Reclamation Directives and Standards (FAC 01-07) regarding examination of normally inaccessible features. These guidelines were developed with the understanding that embankment drain inspections need to be performed prior to the CFR process, similarly to stilling basins or other inaccessible features. As such, the costs associated with the inspection and subsequent documentation is non-reimbursable. Each Area Office should program sufficient funding to accomplish these activities within their Examination of Existing Structures budgets.

B. Comprehensive Facility Review Activities

1. Description of activities to be included in the CFR process The principal engineer will complete an evaluation and review of the embankment drain system, using the inspection report and all of the available design and performance information. This evaluation should be made in light of the considerations contained in sections III and IV of this report as well as any other information that is useful in assessing the embankment drainage system. If findings from the evaluation indicate a failure mode is potentially developing (i.e., material is being transported into the drain pipe) or if the estimated risk warrants further risk reduction actions, the potential failure mode should be reported to the Area Office, Regional Office, and DSO immediately for a decision.

Each evaluation and review will be documented in an *Embankment Drain Evaluation Report of Findings* in the approved DSO reporting format for use in the CFR and Decision Document. A draft report, suitable for peer review, will be completed within 60 days of the completed inspection report. The draft report will be distributed to the peer reviewer and DSO program manager as well as Regional and Area Office dam safety managers for comment. A final report, including peer review signature, will be complete within 90 days of the completed inspection report and before the initial meeting for use by the Senior Engineer in the CFR.

All Embankment Drain Evaluation Reports of Findings should include:

- A summary of the results of the inspection
- A discussion of the failure modes that may be monitored or detected by the embankment drain
- A discussion of the need to perform future actions and follow up activities that should be considered for a formal recommendation by the Senior Engineer and CFR team

- A specific discussion on the need to perform drain cleaning and the need to improve permanent future access to the drain

- A specific discussion of embankment drain monitoring frequency to be considered by the Senior Engineer and CFR team and any recommended changes to the L-23

- A specific discussion of the inspection frequency for the embankment drain system to be considered by the Senior Engineer and CFR team

These considerations **<u>will not</u>** be in the SOD or O&M format (i.e., 200X-SOD-X). The principal engineer's discussions in this report will be based on the considerations of risk, potential failure mode(s), performance, foundation conditions, dam design and construction features, embankment drain design and construction features listed in section III, and the results from the initial CCTV inspection. The principal engineer should build the case for recommendations for future actions and follow-up activities based on these considerations and the additional considerations found in section IV of this report. The principal engineer should address the frequency for future inspections should they be needed (every 6 or 12 years, as with CFR inspections), the need to provide access to inspect the inaccessible portions of the embankment drain system, and the need for cleaning, repair, replacement or abandonment. Regional and Area Office dam safety personnel will review the report and recommendations as part of the normal CFR process. Agreed-upon recommendations will not be entered into the Dam Safety Information System until reviewed and approved during the normal CFR process.

The Senior Engineer for the CFR should present a summary of the *Embankment Drain Evaluation* in the *Evaluation of Design, Analysis, and Construction* section of the CFR Report. The Senior Engineer should include in the DSAT presentation their findings and risk-based SOD or O&M recommendations generated from their review of the embankment drain evaluation for consideration by the decision makers.

The CFR Report of Findings will contain specific recommendations, as appropriate, for future actions and or follow-up activities relative to the embankment drains if appropriate. Follow-up activities may require very specific directions to be followed and issues to consider as related to additional access, cleaning, etc. The Dam Safety Decision Document will identify appropriate funding sources for these activities. Appropriate funding sources may include operation and maintenance, original construction authorizations, SEED, and Safety of Dams (i.e., ISCA).

The CFR Report of Findings should also include a discussion of the schedule for future CCTV inspections and a statement addressing the need for an inspection prior to the next CFR.

2. Estimated cost and funding source Activities completed by the principal engineer as well as the activities completed by the Senior Engineer and CFR team related to the evaluation and documentation process for embankment drains will be included in the normal TSC budget for a CFR. As with any CFR activity, an adjustment to the normal process requires prior approval by the DSO.

C. Follow-Up Activities (If Needed)

1. Description of follow-up activities The scope of follow-up activities could range from cleaning and re-inspection of the embankment drains to major repairs or modifications to the embankment drain system. These actions may be accomplished by O&M staff or may require development of specifications and contracting. Accomplishment of follow-up activities will be consistent with existing policy and practices regarding O&M and major construction activities at Reclamation facilities.

Follow-up activities accomplished by O&M personnel will be documented in an Embankment Drain Follow-Up Activities Report. The Area Office will prepare this report to capture the actions completed; this report will be similar to a construction report. Follow-up activities requiring significant modifications to the facility will be accomplished and documented in accordance with existing practices for design and construction activities at Reclamation facilities.

The report will also be prepared within 60 days of the completion of the activity. Each report may include a list of considerations for future work for the principal engineer to consider in the report of findings. The considerations will not be in a SOD or O&M recommendation format.

Each evaluation and review completed after a follow-up activity is complete will be documented in a Report of Findings (ROF) by the principal engineer in the approved DSO reporting format and made a part of the decision document similarly to an Issue Evaluation ROF. A draft report, suitable for peer review, will be complete within 60 days of the completed Embankment Drain Follow-Up Activities Report. The draft report will be distributed to the peer reviewer and DSO program manager. A final evaluation Report of Findings, including peer review signature, will be complete within 90 days of the completed Follow-Up Activities report. If risk-based SOD recommendations are generated as a result of the review of follow-up activities, then with the agreement of the DSO program manager, the principal engineer will arrange a DSAT meeting for complete discussion of the report of findings. In this case, the report of findings/decision documentation will be prepared and distributed to DSAT members based on guidelines established by the DSO. The need for DSAT meetings should be agreed to by the DSO program manager, principal engineer, and peer reviewer within 15 days of the completed evaluation ROF. The DSAT meeting should be scheduled within 45 days of distribution of the peer-reviewed report of findings.

2. Estimated cost and funding source The estimated cost and funding source for follow-up activities will vary, depending upon the scope and nature of the follow-up activity. As noted above, the funding source for follow-up activities will be identified in the Dam Safety Decision Document for follow-up activity.

III. Technical Considerations for Additional Actions

This section provides the principal engineer with a list of considerations for assessing the need for and frequency of future inspections and/or follow-up activities, such as providing additional access, repair, replacement, abandonment, or cleaning. In the past, embankment drains have only been considered a minor feature in a dam. Based on many years of observation of embankment drain operation, it is evident that embankment drains in many dams were almost an afterthought. Review of records, inspections and performance of embankment drains have shown them to be poorly located, poorly constructed, poorly maintained and/or performing poorly in many instances. Many designers have evidently ignored repair of embankment drains, once constructed. In some instances, poor embankment drains can be directly linked to developing failure modes that were averted by prompt action. In other instances, changing conditions detected by monitoring of embankment drains has led to corrective actions be taken. In one instance, a dam failed, and the first sign of changing conditions was increasing, muddy flow from an embankment drain.

Given this history and the advances in inspection technology, there has been an increasing interest to inspect the embankment drains of existing dams. This interest has resulted in the identification of issues in some dams, warranting modifications to correct a problem.

This interest does not come without a price. CCTV inspection equipment is very expensive to purchase, operate, and maintain. Further, the environment being inspected is typically harsh, and can pose many hazards and obstructions. Although rare, inspection equipment can become lodged in the drain pipe. In addition, due to the harsh environment, inspection equipment can experience breakdown while in the embankment drain system. If CCTV inspection equipment becomes lodged within a drain pipe, it can partially block the pipe, reducing its capacity, and the retrieval process can be expensive and time consuming. If CCTV inspection equipment becomes stuck in totally inaccessible portions of an embankment drain system, complete abandonment and loss of the equipment is possible. For this reason, the operator of any CCTV inspection equipment must be very experienced and have a clear understanding of the capabilities and limitations of the equipment. The operator must be very cautious and should not push the equipment beyond retrievable limits. The ability to recognize inspection limitations is based largely on the operator's skill and experience. The operator should have a thorough background and be very knowledgeable about drain pipe materials, obstructions, defects, and plugging mechanisms. Operators must understand that many embankment systems within dams are not like sewers, where a limited amount of fill may exist over the drain pipe. Accessing stuck inspection equipment within a dam may be very difficult. The equipment may become irretrievable.

Providing additional access to otherwise inaccessible embankment drains it typically even more expensive. Additional access can involve the digging of deep excavations to exhume the embankment drain, inclusion of permanent manholes to permit future inspections, and even adjusting dam operations to accommodate the excavation. The excavation of deep pits can create a significant risk by potentially increasing gradients and causing the onset of internal erosion. Even locating the pipe can prove to be a challenge.

There are too many permutations of dam design, performance, and risk to make this guidance document a "cookbook" that strictly defines if, how, and when future actions or follow-up activities should be recommended for embankment drain systems. This guideline approaches the issues by discussing some of the categories that bracket the problem and providing some specific considerations in each category upon which to base a judgment, as shown in table 2. It is intended that a recommendation for additional activities is based on an evaluation of all the considerations listed under all of the categories. The principal engineer should build a case in light of all categories. Recommendations should be justified by multiple considerations that "lead to a recommendation for future inspections and/or follow-up activities" rather than a single low risk consideration. The following categories are, in general, prioritized from top to bottom. The considerations within each category are also generally prioritized from top to bottom, such that more weight should be given to those listed first. See the decision tree in figure 1 for assistance in using this information.

Table 2.—Categories of considerations for future inspections and/or follow-up activities on embankment drains. Both the categories and their considerations are prioritized from top to bottom.

Category	Considerations leading to a recommendation for future inspections and/or follow-up activities	Considerations leading to no recommendation for future inspections and/or follow-up activities
Embankment drain performance history	• Limited visual inspections indicate structural problems (collapse, deformed, corroded) • Evidence of possible piped material at embankment drain outfall • Embankment drain outfalls not observable • Changes in seepage conditions (i.e., increasing or decreasing) • Velocities in drain pipe capable of continuous material transport (≥0.5 ft/s)	• Embankment drain outfalls are observable • Embankment drains with no flow and no evidence that it is plugged • Embankment drains with exiting seepage, but no evidence of piped material • Limited visual inspection indicates good conditions • Velocities in drain pipe incapable of continuous soil transport (<0.5 ft/s)
Findings from CCTV inspection	• Embankment drain system plugged with soil • Broken, separated, or distressed pipe • Bio-fouling, root intrusion, animal invasion, or mineral incrustation • Sags in alignment observed upstream of wet spots at the embankment	• Good conditions • Structural integrity confirmed

Embankment cross section	• Homogenous dam, that, should erosion into the embankment drain start, there is nothing to stop it • Core and shell material that would easily be carried into a flaw in embankment drain • Cross section that could result in high seepage gradients into the embankment drain • Embankment drain that is located deep within dam close to or under the core (piping could rapidly progress) • Problems found in similar designs in similar settings	• Multi-zoned dam, which would inherently limit the piping potential into a poor embankment drain • Core and shell material that is non-erosive • Core and shell material that is well graded (potentially self-filters any flaw in embankment drain) • Cross section design that controls seepage well and would not have high gradients into embankment drain • Embankment drain located near downstream embankment far from the core

Embankment drain design and construction	• Embankment drain with no surrounding filter or poorly designed filter material • Embankment drain pipe material is weak (potential for embankment loads crushing pipe) or corrodible • Drain pipe joint details prone to problems • Embankment drain constructed with open joints (prone to poor construction control) • Filter material easily eroded into a flaw in the embankment drain	• Embankment drain of strong, non-corrosive material • Good details for embankment drain openings and connection with good construction control • Embankment drain with multistage filter material • Filter can easily maintain piping protection despite flaws in embankment drain

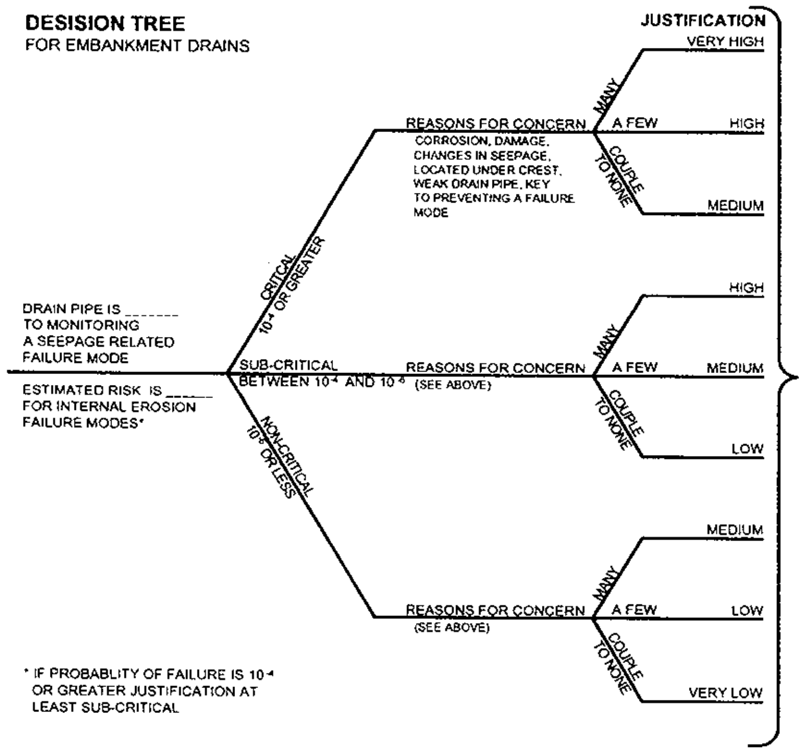
Foundation and geology	• Highly erodible foundation (i.e., dispersive) • Unfavorable geology that could change with time, such as soluble gypsum or internally unstable glacial outwash • Bedrock joint infillings that are erodible • Unfavorable/anisotropic condition due to geologic layering or bedding that creates high pressures downstream of core	• Foundation and geology that are not prone to change with time (i.e., non-jointed granite) • Favorable geology with respect to underseepage (i.e., natural upstream cutoff or steeply dipping non-erodible foundation striking parallel to dam centerline)
Risk/consequences	• See the decision tree in figure 1 and the paragraphs below for details related to this category.	

The following definitions are to be used in the decision tree in figure 1:

- *Critical.* - An embankment drain is considered "critical" to monitoring if the embankment drain is the primary defense against a seepage-related failure mode. For example, an embankment drain system is installed to collect foundation seepage that had been previously transporting soil particles and no other protection against the failure mode exists. Another example of "critical" is if it is judged that failure of the drain pipe (i.e., due to corrosion) would likely initiate a failure mode for which the dam and/foundation has no other defense to stop it.

- *Sub-critical.* - An embankment drain is considered "sub-critical" to monitoring if the drain is considered a key component of multiple defenses against seepage-related failure modes. For example, a drain system that is immediately downstream of a positive cutoff trench that extends to competent bedrock. A "sub-critical" drain pipe is typically located well within the body of the dam. Failure of a "sub-critical" drain pipe would not likely initiate a failure mode but may cause distress and be rather expensive to repair.

- *Non-critical.* - An embankment drain is considered "non-critical" to monitoring if its only function is to prevent the occurrence of unsightly boggy areas at the toe of the embankment. For example, a shallow embankment drain system that is located near the toe of an embankment with an effective cutoff trench to competent bedrock. A "non-critical" embankment drain typically collects no seepage or only minor seepage under full reservoir conditions.



"DO NO HARM"

JUSTIFICATION	INSPECTION FREQUENCY*	ENHANCE MONITORING	PERFORM DRAIN CLEANING	MAKE IMPROVEMENTS TO ACCESS	REPAIR OR REPLACEMENT OF DRAIN	ABANDONMENT OR GROUTING OF DRAIN
VERY HIGH	EVERY 6 YEARS	DO IF EXISTING NOT THE BEST POSSIBLE	DO IF NEEDED AND CAN BE DONE WITHOUT HARM (EVERY 6 YEARS)	CONSIDER STRONGLY IF CAN BE DONE WITHOUT HARM	CONSIDER STRONGLY IF CAN BE DONE WITHOUT HARM	RARELY, ONLY IF A LOT CONCERNS AND LIKELYHOOD OF SUCCESS WITHOUT HARM IS HIGH
HIGH	EVERY 6 YEARS	DO IF EXISTING NOT THE BEST POSSIBLE	DO IF NEEDED AND CAN BE DONE WITHOUT HARM (EVERY 6 YEARS)	CONSIDER MODERATE EFFORT IF CAN BE DONE WITHOUT HARM	CONSIDER MODERATE EFFORT IF CAN BE DONE WITHOUT HARM	RARELY, ONLY IF A LOT CONCERNS AND LIKELYHOOD OF SUCCESS WITHOUT HARM IS HIGH
MEDIUM	EVERY 12 YEARS	DO IF EXISTING NOT CONSIDERED ADEQUATE	CONSIDER IF MANY REASONS FOR CONCERNS RELATED TO PLUGGING (EVERY 12 YEARS)	CONSIDER ONLY IF EFFORT MODERATE TO SIMPLE AND EASY	CONSIDER ONLY IF EFFORT MODERATE TO SIMPLE AND EASY	CONSIDER IF MANY CONCERNS RELATED TO PERFORMANCE, CONDITION AND DESIGN AND CAN BE DONE WITHOUT HARM
LOW	ONLY IF CHANGES TO PERFORMANCE NOTED I.E. SINKHOLE	DO IF EXISTING NOT AT LEAST A TYPICAL WEIR, AND SIMPLE TO DO	CONSIDER IF MANY REASONS FOR CONCERNS RELATED TO PLUGGING (EVERY 12 YEARS)	ONLY IF EFFORT SIMPLE AND EASY	ONLY IF EFFORT SIMPLE AND EASY	CONSIDER IF VERY CONCERNED ABOUT POOR PERFORMANCE
VERY LOW	ONLY IF CHANGES TO PERFORMANCE NOTED I.E. SINKHOLE	ONLY IF SIMPLE TO DO	RARELY, ONLY IF SIMPLE AND EASY	RARELY	RARELY	RARELY

* If poor performance such as dirty flow is observed conduct inspection as soon as possible.

"DO NO HARM"

Figure 1.—Decision tree for embankment drains.

IV. Additional Considerations for Follow-Up Activities

This section provides additional considerations and guidance for recommendations related to follow-up activities beyond additional inspections. Alternatives include no additional actions, cleaning the embankment drain pipes, providing enhanced access to the embankment drains, repairing damaged embankment drains, replacing the embankment drain system, and abandoning the embankment drain system. All follow-up activities beyond normal operations and maintenance, are subject to appropriate NEPA and National Historic Preservation Act (NHPA) compliance activities.

A. No Additional Activities

The guiding principle for decisions related to embankment drains should be "Do No Harm." A decision to do nothing for an embankment drain may be appropriate in cases where it is judged to have little importance to the performance or monitoring of the performance of the dam, where flows are small or nonexistent (and lack of flow is not due to plugging or damage to the embankment drain), where there is a risk of doing harm to the dam, or where the dam has been loaded to design capacity many times with no apparent adverse performance relative to seepage and drainage.

B. Embankment Drain Cleaning

When cleaning, embankment drains remember to "Do No Harm." The justification for cleaning an embankment drain system should be based on an evaluation of the considerations contained in section III, all other pertinent information, and the following considerations.

The safety of the personnel carrying out the cleaning activities is paramount. Proper fall protection, ventilation and other safety measures should be well planned ahead of the operations. A job hazard analysis should be prepared.

Recent CCTV inspections have revealed that bio-fouling, mineralization, and/or soil buildup in embankment drains is common. Cleaning can remove bio-fouling, mineral incrustation, roots, or soils deposits. Caution must be exercised in each step of the cleaning process to prevent damage. Before attempting to remove soil deposits, consider if they are benign, like those that enter a pipe during the development of the filter, or if their removal could initiate more soil movement and make the condition worse.

Cleaning of embankment drain systems is not yet routine. Most embankment drains have never been cleaned, and based on their performance, cleaning may not be justified. CCTV inspection should precede any cleaning attempt, to ensure that cleaning will not degrade existing conditions. To date, Reclamation has limited experience cleaning embankment drains. The proper method of cleaning an embankment drain will vary according to the conditions within the pipe and the condition of the pipe. For instance, low pressure/high volume flow is best suited for sediment removal and high pressure/low volume flow is best suited for root or mineral incrustation removal. In some cases, both might be required. However, the condition of the pipe is paramount for any cleaning attempted, and this may actually govern the cleaning method selected at a given site. The orientation of individual jets on the nozzle of the cleaner can also be varied, depending on site conditions.

It is typically difficult to ascertain how effective the cleaning has been, due to limited instrumentation and variations in embankment drain flows caused by factors other than the reservoir, such as infiltration from precipitation. However, follow-up CCTV inspection after cleaning that used high pressure jet washing has shown that the bio-fouling and mineral incrustation was generally removed from the interior surface and pipe openings. Some improvement of discharge from the embankment drain pipe is typically observed. No determination could be made as to the extent of the plugging mechanism remaining in the backfill materials surrounding the pipe.

Any cleaning system used on an actual embankment drain should have been proven to be effective in a similar situation and on similar pipe materials. If a new cleaning system is used, it should be tested on a piece of drain pipe similar to the drain pipe to be cleaned to ensure the process will not damage the pipe.

The recommended process for embankment drain cleaning generally includes the following six steps:

1. Record all pertinent information, including measuring embankment drain outflows, reading all piezometers and observation wells, and walking the alignment of the embankment drain to observe the preexisting conditions.

2. Perform an initial CCTV inspection to document existing conditions.

3. Test the cleaning system on the first short segment of pipe.

4. In cleaning the remainder of the pipe, use care to observe the entire process, including advancement rates, effluent, etc. Steps 2 through 4 may require an iterative process to ensure that cleaning procedures are not damaging previously un-inspected portions of the embankment drain.

5. Re-inspect the pipe using CCTV and record all other pertinent information again. This could be completed by the contractor doing the cleaning, if they have appropriate CCTV inspection equipment.

6. Prepare a cleaning report within 60 days after cleaning, documenting all information needed for future cleanings, if needed, and information beneficial to an evaluation of the cleaning by others. Disseminate copies of the cleaning report to the principal engineer and other appropriate parties.

See *Drainage for Dams and Associated Structures* (2004) [1] for case histories, details and considerations associated with the cleaning of embankment drain systems.

C. Improving Access

Reclamation's CCTV inspection equipment is limited by the length of cable tether and by sharp bends in the drain pipe. The same is true of drain cleaning equipment. In general, the CCTV inspection equipment can travel and inspect up to 1,000 feet from the access point (under ideal conditions). Drain cleaning equipment can clean up to 1,000 feet of drain, depending on the grade of the pipe and its smoothness. Many of Reclamation's dams include thousands of feet of embankment drains with no intermediate access points. Access is further complicated by sharp bends in the embankment drain alignment. Sediment accumulation, roots, organic debris, or damaged pipes can further limit access to the embankment drains. These problems may preclude the possibility of inspection, monitoring, or maintenance of significant portions of the embankment drainage feature.

The cost and feasibility of improving access to embankment drains warrants careful consideration of the need for such access. When evaluating the need to improve access to the embankment drain system, the following factors should be considered, in addition to those considerations listed under each category in the previous section.

1. Constructability Constructability will have a major influence on the decision to provide additional access to an existing embankment drain system. The location and configuration of embankment drains varies throughout Reclamation's inventory of dams. Embankment drain alignments near the downstream toe of embankments will generally be much easier to access than alignments under the crest of the structure. Some embankment drain systems have multiple alignments parallel to the crest of the dam, possibly necessitating multiple access points. Others are constructed as a grid under the embankment. Access constructability considerations include:

- Potential to cause harm
- Depth of excavation
- Disruption to the embankment and foundation
- Need for unwatering and dewatering
- Need for reservoir restrictions or need to schedule the work during the normal reservoir filling and drawdown schedule to facilitate construction

- Number of access points needed

2. Alternatives for providing access to embankment drains The following provides an array of alternatives to provide reasonable access to embankment drains. The selection should be based upon evaluation factors listed above.

- *Construct or expose embankment drain outfall.*—Many structures have embankment drains with buried outfalls. If the embankment drain is located as a result of exploration, constructing an outfall would be considered the minimum access necessary to provide monitoring capability. This may be appropriate in cases where little or no history of flow is apparent in the pipe or surrounding area.

- *Construct access at junction of embankment drain and outfall.*— Construction of an access point at the juncture of the outfall and drain can be accomplished either by casing the excavation, which may be appropriate if the junction is located well within the embankment, or by normal excavation if the junction is located near the downstream toe of the embankment. Once this access is established, additional inspection can be conducted, and intermediate access points can be located, if necessary.

- *Locate access at upstream terminal points of embankment drains.* — The upstream end of the embankment drain can be utilized as an access point to the embankment drain. The advantages of constructing access at the upstream end can include:

  - Shallower excavation

  - Less reservoir loading at the point of excavation

  - Once established, can be used to locate intermediate points of access

  Disadvantages include difficulty in locating the upstream end of the embankment drains. Generally, as-built drawings that accurately locate the elevation or alignment of the embankment drains do not exist. Locating the embankment drains often requires extensive exploratory excavation. If the drain pipe is constructed of corrugated metal pipe (CMP) or other metal, and the expected depth to the embankment drain is relatively shallow, a metal detector may help in locating the embankment drain.

- *Other considerations.*—When implementing recommendations to provide improved access to embankment drain features, the following items should be considered:

  - *Flow and sediment monitoring.*—Access points should include provisions for measuring flow and monitoring sediment movement through the system. The access points should include sediment traps and flow measurement devices.

- *Material sampling.*—Collect and analyze samples of surrounding embankment, foundation, and drain envelope material when installing new access points to assess their erodibility and determine if filter criteria are met.

- *Personnel safety.*—The access points should include provisions for safe entrance and egress for personnel to measure flow and sediment accumulation.

- *Configuration.*—The design of improved access must take into consideration the size requirements needed to accommodate use of CCTV inspection equipment. For further guidance on accommodating inspection equipment, see appendix C in "Drainage for Dams and Associated Structures (2004)".

D. Repair or Replacement of the Embankment Drain

Many CCTV inspections have revealed damaged or collapsed drain pipe. In many cases, the drain pipes appear to have failed during original construction due to equipment travel over the embankment drain alignment, inadequate pipe support, pipe material defects, or other factors. In other cases, the embankment drains are in a state of failure due to the deterioration of the drain pipe, differential settlement along the alignment of the embankment drain, or other factors. Replacement of the embankment drain may be an appropriate response in these situations. The following provides a summary of considerations for repairing or replacing the embankment drain.

1. Failure mode Specific considerations related to review and consideration of seepage and drainage related failure modes are addressed earlier in this guideline. If considering replacement of an embankment drain, the designer should consider relocating the embankment drain alignment, elevations, outfalls, etc. to better address seepage conditions at the dam or to reduce or eliminate potential failure modes associated with the drainage feature.

2. Address why the embankment drain failed In repairing or replacing the embankment drain, the designer should consider why the embankment drain failed. Was it a result of poor construction practices? Was it related to the pipe material? Did the embankment drain plug due to problems with the drain envelope material? The repair or replacement should be designed to address these issues.

3. Design considerations Embankment drain repairs or replacements offer excellent opportunities to provide additional access to an embankment drain system. Access points should be added at least every 1000 feet (if reasonable) to facilitate inspection, cleaning, maintenance, and monitoring activities. Access points should include features for monitoring flow and material movement within the embankment drain system, personnel safety features, and access for inspection and cleaning equipment. Appendix A of Reclamation's *Drainage for Dams and Associated Structures (2004)* provides more guidance on embankment drain design.

4. Quality assurance As noted earlier, many embankment drain failures are the result of construction activities. Embankment drain repair or replacement projects should include provisions for thorough inspection during construction and following completion of construction. A CCTV inspection of the embankment drain alignment at the completion of construction is required. As-built drawings with accurate surveys must also be completed as part of the modifications.

E. Abandonment/Grouting of the Embankment drain System

This may be an appropriate alternative in cases where the drainage is not considered a critical feature in the performance of the dam, where historic flows have been small or nonexistent, and where the results of the inspection reveal damage or failure of the embankment drain system that could lead to a future "incident," and abandonment can not cause harm.

1. Failure mode As noted above, this alternative would likely be most appropriate in those cases where there is not a likely failure mode that would lead to failure of the embankment. Rather, this alternative could be selected to prevent development of an "incident," such as development of a depression over the alignment of the embankment drain. It may also be an appropriate alternative when replacing an embankment drain system. Additional guidance related to review and consideration of seepage- and drainage-related failure modes is addressed earlier in this report.

2. Staging When making the decision to abandon or grout the embankment drain, the designer should consider temporary measures to evaluate the impact of plugging the embankment drain. The designer should assess all sections of the embankment drain to make sure that plugging would not cause detrimental pressures to rise. One alternative would be installation of a packer to temporarily plug one or more sections of the embankment drain. This would allow evaluation of changes in seepage conditions prior to implementing permanent measures to plug the embankment drains.

3. Alternatives Options for plugging the embankment drain system include filling the embankment drain and outfall pipes with sand or grouting the embankment drains. The sand alternative would have the advantage of being a less permanent measure, in that the sand could be jetted from the embankment drain if changing conditions warrant such an action. The existing conditions within the drain pipe, as observed with CCTV inspection, may govern the alternative selected.

References

[1] *Drainage for Dams and Associated Structures,* Bureau of Reclamation, Technical Service Center, 2004

[2] *Design of Small Dams* (1960 edition), Bureau of Reclamation, First Edition, 1960.

[3] *Review/Examination Program for High- and Significant- Hazard Dams,* Reclamation Directive FAC 01-07, Bureau of Reclamation, July 20, 1998.

Appendix A

Salient Features of a Good Embankment Drain System

- The system is located such that a collapse or damage of the drain pipe would not result in a serious condition.
- Design adequately addresses the uncertainties associated with foundation properties, predicted seepage quantities, and variations in gradations.
- Designed with excess flow capacity to carry seepage and prevent boggy areas at the embankment (This includes the filter system as well as the pipes for conveyance). Typically, the drain pipes increase in diameter from their highest location to the outfall.
- Located at a depth to effectively intercept seepage.
- Designed with an adequate number of access points for inspection and maintenance. Designed to accommodate CCTV inspection, see appendix A of Reclamation's *Drainage for Dams and Associated Structures* for more details.
- Envelope materials are properly designed to filter base soils (Typically, a two-staged filter is used, which increases capacity and prevents plugging of perforations).
- The dimensions of filter zones make them easily constructible, and details of embankment drains are clear for construction.
- Embankment drain pipes are sloped to maintain a minimum velocity and prevent plugging from biofouling.
- Materials with adequate durability and strength are used.
- Perforations or slots are designed to filter and yet not plug (Can test in lab).
- Specifications address site specific issues.
- General specifications that are used for standard features, such as the pipe materials or aggregate durability, are proven to result in a high quality embankment drain system.
- Constructed according to specifications and with care to ensure no damage.

- Adequate flow measurement devices associated with system that also cause a stilling effect to the flow that allows for the detection of soil particle migration. It is typical to isolate flow measurements, such as isolating the right abutment embankment drain from the left, or isolating areas of special concern, such as in the vicinity of shear zones.

- Screen installed on outfall to prevent animal invasion.

- Well documented as-built drawings of the embankment drain system and clear maintenance and inspection guidance. Guidance includes the control of vegetation and trees near the embankment drain systems whose roots could result in plugging.

- Proper installation of HDPE pipe requires good compaction and quality control of the backfill to ensure good support under the haunches. Proper installation protects against stress cracking. These stress concentrations can lead to premature failure, especially if the pipe does not have sufficient stress crack resistance (SCR).

- When using HDPE for embankment drain applications, a preliminary CCTV inspection should be performed when 3 to 5 feet of backfill has been placed over the pipe. The purpose for this inspection would be to identify and repair any abnormalities, cracks, bulges, etc. before construction is complete.

- Another CCTV inspection should be performed when the final backfill loading over the pipe is completed. CCTV inspection should be performed prior to the contractor pulling the torpedo-shaped plug or pig through the pipe and prior to any cleaning. The purpose for this inspection would be to identify any abnormalities, cracks, bulges, etc. that may have developed since the preliminary inspection and to document the "as-built" condition to which future inspections will be referenced. CCTV inspection could replace the need for pulling the plug or pig through the pipe.

Appendix B

An Incomplete list of Case Histories of Findings from Incidents and Recent CCTV Embankment Drain Inspections

1. Big Bay Dam (Lamar County, Mississippi): Dirty flow from a drain pipe was observed hours before failure. The engineer on the job observed a concentrate seep at the downstream toe of the dam flowing about ½ to 1 gallons per minute and transporting a few grains of fine sand. The engineer left the site after observing no significant change in the seepage condition. Within 30 minutes of his departure he was called back to the site, as conditions had worsened, only to see the breach progress rapidly back through the embankment. It took approximately 85 minutes from the time the engineer left the site until the breach formation broke through the crest and uncontrolled release of the lake began. This is an example of where flow from an embankment drain provided the first indication of impending failure. From "Big Bay Dam - Evaluation of Failure", April 27, 2004, by Timothy R. Burge, P.A., Inc, Consulting Engineers, Hattiesburg, Mississippi.

2. Sherman Dam: Sinkholes formed over the original embankment drain and thus the embankment drain was grouted and replaced with a new embankment drain. More recently a separation was discovered as a segment of the outfall pipe had become separated. Recurring sinkholes happen over the old embankment drain.

3. Bonny Dam: Original embankment drain grouted and replaced. Boils occurred in the bottom of the excavation for the new drain. Emergency fill was placed in the trench to prevent blowout and prevent further damage to the foundation. Dewatering was then used to control the ground water and relieve pore pressures prior to resuming excavation.

4. Davis Creek Dam: Failure of drain pipes most likely during original construction discovered by CCTV. Damaged sections excavated and repaired.

5. Cawker City Dike (Lagoon drain): Asbestos-bonded CMP failed due to corrosion. The drain was replaced recently with HDPE pipe.

6. Enders Dam: During first filling of the reservoir a sinkhole was observed in the downstream slope as a result of soil materials being transported into the embankment drain that was missing the end plug.

7. Pablo Dam: The embankment drain, originally located near the toe of the embankment, ultimately was located near centerline of the dam as a result

of raising the dam by moving the crest and extending the embankment in the downstream direction. The embankment drain failed leading to a 50-yd^3 sinkhole in the crest of dam.

8. Deer Flat Dam: An incident occurred during the initial refilling of the reservoir after modifications in the 1990's. A large embankment drain and filters had been added at the downstream toe as the primary defensive measure against internal erosion of the foundation soils. During refilling large quantities of sand were observed in the embankment drain system. Later review of the problem indicated that construction equipment had caused removal of filter materials from the side of the trench and resulted in the gravel portion of the drain being placed directly in contact with incompatible foundation materials. An emergency was declared and the damaged section of the embankment drain was exhumed and repaired.

9. Clark Canyon Dam: During first operation into flood surcharge in 1984, cloudy flow was observed coming from the embankment drain outfall. Sinkholes developed over the embankment drain alignment. The embankment drain was excavated and replaced, and a field drain system was added further downstream to collect and filter uncontrolled seepage that was bypassing the embankment drain.

10. San Justo Dam: CCTV inspection has revealed numerous failed sections of embankment drain that may have been damaged during construction or during seismic events.

11. Ochoco Dam: During excavations for major modifications to the embankment, the drain pipe was found to be collapsed in one area and nearly completely blocked with a large root in another area. The old embankment drain was removed and replaced with a new embankment drain system.

12. Pishkun Dike: Deterioration of concrete, likely the result of freeze-thaw, associated with an air vent for the outlet works structure led to a sinkhole in the crest of the dam. This is an example of how deterioration of pipe materials can lead to an unexpected incident needing costly repairs. It is envisioned that should deterioration be observed during CCTV inspections of embankment drains that timely evaluations could be completed and less costly repairs done, if warranted.

13. Lake Alice Dam: The original embankment drain was plugged nearly completely with soils from the foundation. This embankment drain was excavated and replaced with a stability berm and a blanket drain. This fix was not completely successful in collecting and controlling all the seepage, so a new embankment drain was added in 1996. Perforations in the 1996 drain pipe plugged, leading to wet areas on the existing berm. The embankment drain was repaired a second time by including a gravel envelope around the pipe, it has worked successfully since then.

14. Horsetooth Dam: Due to increasing seepage from the embankment drain and at the downstream toe of the dam and the presence of a 90-degree bend in the alignment that prevented access beyond this point from the downstream end, access was added at the upstream end of the drain. The access was provided by construction of a manhole by the irrigation district. After access was provided, a CCTV inspection revealed the embankment drain pipe was broken in one area and that subsidence of the soils beneath the pipe had resulted in a sag in the alignment, which caused the flow collected in the pipe upstream of the sag to exit the pipe and surface at the downstream toe of the embankment rather than from the outfall of the embankment drain. This drain pipe was later removed to accommodate major modifications, and a new drain pipe was added further downstream to allow for the collection and monitoring of seepage.

15. Steinaker Dam: Soils from possibly the foundation and/or the embankment were observed exiting the embankment drain during first filling. Rather large seepage flows were being collected by the embankment drain as seepage was passing through the left abutment. As a result of the soil being removed, two approximately 20-foot diameter sinkholes formed in the downstream slope of the dam. Grouting was completed to successfully reduce the seepage through the abutment and fill the voids in the foundation that were formed by the seepage transporting soil into the embankment drain.

16. Unknown dam: An earthquake has caused collapse of a CMP pipe in several areas as ground motions rippled through the dam site.

Detailed Case Histories of Inspections

Bonny Dam

Bonny Dam is located on the South Fork of the Republican River near Hale, Colorado. Bonny Dam is an embankment with a structural height of 158 feet and a hydraulic height of 93 feet. The crest of the dam is 30 feet wide and 9,200 feet long at elevation 3742.0 feet. The dam was completed in 1951.

The toe drain system consists of the original abutment toe drains, additional drains constructed in 1955, interim toe drains constructed in 1988, and drains constructed during the 1994 modifications. The original toe drain system was located on both abutments and consisted of 12-inch diameter clay pipe with open joints. The total length of the original north toe drain is approximately 1,050 feet. The original right abutment toe drain has been abandoned and was filled with sand in 1994 to prevent the possibility of piping. The drains constructed in 1955 are 8-inch-diameter tile drains located parallel to and left of the outlet works at the base of the slope. The length of these drains is approximately 250 feet. The interim drains constructed in 1988 are corrugated 12- and 18-inch diameter HDPE pipe. The 1988 drains are located near the original streambed at the base of the slope and are parallel to and downstream of the drains constructed in 1994 for a good portion of the toe of the dam. The length of these drains is approximately 2,850 feet. The interim drains are still active drains. The drains constructed in 1994 consist of 12-, 15-, 18-, and 24- inch diameter HDPE pipe. The toe drain system had never been inspected prior to the October 2003 CCTV inspection. The toe drain system has never been cleaned. The reservoir water surface elevation during the CCTV inspection was approximately 3657.4 feet on October 28, 29, and 30, 2003 and 3657.3 on November 7, 2003.

Water samples were taken from manholes at dam stations 50+40 (right abutment toe drain, 1994 series), 66+50 (interim toe drain, 1988 series), and 70+96 (toe drain outlet, 1994 series). The water samples were sent to the Ecological Research and Investigations Group, Technical Service Center, Denver, Colorado for bacterial and chemical analysis. The results of this analysis are reported in a memorandum dated January 13, 2004.

On October 28, 29, and 30, 2003 and November 7, 2003, the Technical Service Center's staff performed a CCTV inspection of the toe drain system at Bonny Dam at the request of the Nebraska-Kansas Area Office.

The Technical Service Center's staff utilized VersaTrax parallel and inline camera-crawlers, and a Subseas camera on coiled wire snake and on loading poles for the CCTV inspection at Bonny Dam. The VersaTrax parallel camera-crawler is a remotely controlled tracked vehicle used to inspect pipes with diameters 15 inches and larger. The VersaTrax inline camera-crawler is a remotely controlled tracked vehicle used to inspect pipes with diameters between 6 and 14 inches. The Subseas camera is used when a camera-crawler cannot enter the pipe.

Based on the CCTV inspection and technical evaluation of the inspection videotapes, the following conclusions were reported in the Report of Findings (ROF):

- The majority of the lengths of most sections of toe drain were CCTV inspected. Approximately 42 percent of the original north toe drain, 55 percent of the right abutment toe drain to the right of the manhole at dam station 42+26, and 12 percent of the two spillway drains were inspected. Significant accumulations, sedimentation, and calcium carbonate precipitation, as well as pipe grade and length prevented complete inspection of some sections. Approximately 8,490 feet of the 10,900-foot system (about 78 percent) was actually inspected.

- A section of clay tile pipe appeared to be collapsed approximately 192 feet upstream from a manhole.

- The original north toe drain was laid with open joints. A significant amount of sediment has entered the drain from the open joints.

- Most of the toe drain sections with pipe perforations exhibit signs of minor to moderate calcium carbonate precipitate. Some drains had significant calcium carbonate precipitate in the pipe perforations.

This CCTV inspection ROF was recommended to be reviewed as part of the next Comprehensive Facility Review (CFR) for Bonny Dam.

Trenton Dam

Trenton Dam is located on the Republican River about 22 miles west of McCook Nebraska. The dam was completed in 1953 and is a zoned earthfill embankment with a structural height of 144 feet, a hydraulic height of 80 feet, a crest width of 30 feet, and a crest length of 8,600 feet. The crest at elevation 2793.0 feet, is asphalt-surfaced Nebraska State Highway No. 25. A gated, concrete-lined spillway is located on the left abutment and is controlled by three 42- by 30-foot radial gates. Two river outlet works conduits are located in the base of the intermediate spillway piers. Flow is controlled in each outlet by 6- by 7.5-foot tandem high pressure emergency and regulating gates. A canal outlet works is located near the right abutment and includes an intake structure, a 5.5-foot diameter upstream concrete conduit, a gate chamber, an 8-foot 2-inch diameter downstream horseshoe conduit containing a 56-inch diameter steel outlet pipe, a downstream control house structure, and a stilling well. The majority of the dam was constructed of impervious material, with the downstream toe being constructed of pervious material. Because of the pervious material at the toe of the dam and pervious alluvial foundation, including abutments, toe drains were not provided, except in short sections of the dam right of the canal outlet works on the right abutment and left of the spillway on the left abutment.

The drains at the site include right and left toe drains, embankment drains that drain the embankment south of the canal outlet works discharge channel, and spillway drains. The drains had never been cleaned or inspected prior to a October 2004 inspection. The reservoir water surface elevation during the CCTV inspection was 2729.10 feet.

On October 25 and 26, 2004, the TSC's staff performed a CCTV inspection of the drains at Trenton Dam at the request of the Nebraska-Kansas Area Office. The TSC's staff utilized a VersaTrax inline camera-crawler and a Subseas camera to perform the CCTV inspection. The VersaTrax inline camera-crawler is a remotely controlled, tracked vehicle used to inspect pipes with diameters between 6 and 14 inches. The Subseas video camera is used to inspect pipes with diameters as small as 2 inches or pipes with obstructions that prevent use of a tracked camera-crawler. The Subseas video camera is attached to loading poles or a coiled-wire snake and manually advanced through the pipe.

Based on the CCTV inspection and technical evaluation of the inspection videotapes, the following conclusions were reported in the ROF:

- The majority of the lengths of most sections of toe drain could not be inspected. Approximately 200 feet of the estimated 1,690-foot system (about 12 percent) was actually inspected. Approximately 580 feet of the 1,030-foot known length of spillway drain (about 56 percent) was inspected. Some drains were not shown on the drawings and had no estimated lengths. Of these, 73 feet of additional spillway drain was inspected, and 103 feet of drain in the west bank of the canal outlet works was inspected. All the existing outfall portals were not shown on the drawings. These were located from available pictures. Most drains inspected had elbows, tees, "Y" bends, or other bends in the drain pipe a relatively short distance upstream of the outfall. The camera-crawler and Subseas camera being used for the inspection could not be advanced beyond these obstacles.

- A damaged area at a joint 31 feet upstream from the right toe drain exit portal was encountered. The joint was separated by about 4 inches and was offset about 3 inches deep. There is evidence that material has been eroded from behind the pipe. Additional separated and offset joints were encountered 130 and 165 feet upstream of the exit portal.

- Significant sediment (pipe about ¾ full) was encountered in the spillway chute slab drain, approximately 14 feet upstream of the exit portal on the right side of the spillway.

- A minor shape failure was encountered 5 feet upstream from the exit portal for the spillway chute slab drain. The flow area was reduced by approximately 25 percent.

- An extensive shape failure was encountered 5 feet upstream of the exit portal for the left toe drain. The flow area was reduced by approximately 80 percent.

The CCTV inspection ROF was recommended to be reviewed as part of the Comprehensive Facility Review for Trenton Dam.

Appendix C

Design Considerations to Accommodate CCTV Inspection Equipment

The following has been adapted from *Drainage for Dams and Associated Structures (2004).*

The following general guidelines are based on the results of the performance testing of CCTV equipment within double-walled HDPE pipe done by Reclamation's Technical Service Center in 2002. All performance testing in this research program was based on the assumption that the camera-crawler would travel up the pipe from a downstream location. embankment drain designs that provide an upstream access location from which the camera-crawler can gain entry allow for improved cable tether pulling capacity, since the camera-crawler can move downward on a sloping decline. Sloping declines generally do not result in camera-crawler traction issues. For the camera-crawler backout process, the transport vehicle has a free-wheeling clutch mechanism on the track unit that allows for high speed retrieval either manually or by a cable take-up reel. Although not tested in this research program, the upstream access location would also benefit camera-crawler navigation around pipe bends and allow for the use of steeper invert slopes, since the effect of cable drag would be lessened. Providing upstream access locations would be especially important where steeper invert slopes may be required, such as on abutments.

- *Pipe diameters.*—The minimum recommended pipe diameter to successfully accommodate CCTV equipment is 8 inches. Although camera-crawlers are available for pipes smaller than 8 inches, they are very limited in cable tether pulling capacity and generally do not have sufficient traction for use in embankment drain inspection. In addition, the cameras typically only have a fixed lens, and the transport vehicle is not steerable. Camera-crawlers used in pipes with diameters between 8 and 12 inches generally have cameras with some pan, tilt, and zoom capabilities, but generally are not steerable. Camera-crawlers used in pipes with diameters of 15 inches or larger are steerable, have a greater cable tether pulling capacity, and have cameras that can provide a wider array of optical capabilities, including pan, tilt, and zoom. Where practical, the use of pipes with diameters 15 inches or larger is strongly encouraged. This allows for the use of more powerful and versatile camera-crawlers.

- *Pipe bends.*—The maximum recommended bend angle to successfully accommodate CCTV equipment is 22.5 degrees. In pipes with diameters of 8 and 10 inches, the camera-crawler cannot be navigated around bends greater than 45 degrees, since the camera cannot clear the pipe crown as it travels through the bend. If sharper bends are required in pipes with diameters of 8 and 10 inches, a series of 22.5-degree bends is recommended.

Each bend should be connected to a minimum 5-foot length of pipe to allow the camera-crawler to navigate around the bend segment and provide adequate crown clearance. Pipes with diameters of 12 inches or larger can have bends that exceed 22.5 degrees, but drag friction then reduces the cable tether pulling capacity by as much as 75 percent.

- *Invert slope inclination.*—The maximum recommended invert slope inclination to successfully accommodate CCTV equipment is 5 degrees. The difference in invert slope inclination between flat and 10 degrees can reduce cable tether pulling capacity by as much as 70 percent, depending upon the pipe diameter, degree of pipe bend, and the invert condition. Flat to 5-degree invert slopes would appear to be the most reasonable inclination. Slopes with inclinations greater than 10 degrees are not recommended, due to the significant loss of traction that occurs when camera-crawlers are pulling long cable tethers. If slopes greater than 5 degrees are required, upstream access locations should be provided within the pipe.

- *Distance between manholes or access entry locations.*—The maximum distance between manholes or access entry locations can range between 500 and 2,000 feet, but highly depends upon the pipe diameter, bends, invert slopes, and invert conditions. The designer will need to take these limitations into account when selecting the appropriate distance between manholes or access entry locations. In pipes with diameters of 8, 10, and 12 inches, the maximum distance should not exceed about 1,000 feet. This assumes that access is available on both ends of the pipe. If access will only be available on the downstream end of the pipe, then the maximum distance should be limited to about 500 feet. In pipes with diameters of 15 and 18 inches, the maximum distance should not exceed about 2,000 feet. This assumes that access is available on both ends of the pipe. If access will be only be available on the downstream end of the pipe, then the maximum distance should be limited to about 1,000 feet. There are graphs available [1] that provide more information on how pipe diameter, bends, invert slopes, and invert conditions affect the cable pulling capacity of camera-crawlers and the maximum distance between manholes or access entry locations.

Appendix D

Summary of Findings from Embankment Drain Inspections

The following has been adapted from *Drainage for Dams and Associated Structures (2004).*

The Bureau of Reclamation's Technical Service Center has been performing closed circuit television (CCTV) inspection of embankment drain systems as part of Reclamation's dam safety program since about 2000. CCTV has also been used to perform inspections of wall drains, structural underdrains, pressure relief wells, siphons, pipelines, outlet works and spillway conduits, gates, and valves. The TSC has provided CCTV inspection services to many federal and State agencies.

CCTV inspection equipment consists of a video camera attached to a self-propelled transport vehicle (crawler). The transport vehicle and camera are commonly referred to as a camera-crawler (see fig. D-1). The camera-crawler can be configured for a variety of pipe applications. An operator remotely controls both the transport vehicle and camera. The camera can provide both longitudinal and circumferential views of the interior of the pipe being inspected. Video images are transmitted from the camera to a television monitor, from which the operator can view the conditions within the pipe. The video images are recorded onto videotape, compact disc, or digital versatile disc (DVD) for technical evaluation and documentation (Report of Findings). The operator can add voice narrative and alphanumeric captions or notations as the inspection progresses.

The TSC performed a series of tests in 2002 to evaluate the performance capabilities using camera-crawlers in double-walled HDPE pipe. The results of the performance tests served as the basis for the development of design guidance on acceptable pipe diameters and bends, invert slopes, and distances between manholes or access entry locations required to accommodate CCTV inspection. The design guidance is generally applicable for use with other pipe materials. See the Bureau of Reclamation's *Drainage for Dams and Associated Structures* for a

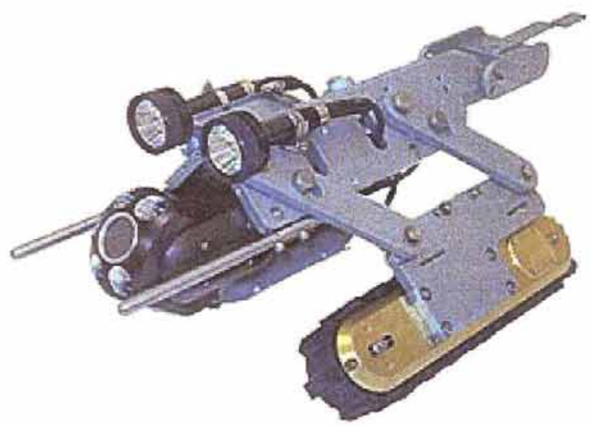


Figure D-1.—Camera-crawler used for CCTV inspection.

summary of embankment drain design guidance to accommodate CCTV inspection equipment, as well as appendix C of this report.

Sometimes an embankment drain pipe is so small that a camera-crawler cannot be used, or obstructions or invert conditions exist within the pipe that prevent the transport vehicle from traversing the pipe. For these types of situations, small color cameras (1.5 to 3 inches in diameter) can be attached to metal or plastic poles (often referred to as push poles) and manually pushed up the pipe. Push poles are normally used for straight sections of pipe. The use of push poles for advancement is generally limited to about 400 feet of pipe length. If bends exist in the pipe, a flexible snake device (spring steel wire, coiled wire, or flexible polypropylene-jacketed fiberglass push rod) can be used instead of the push poles. The color cameras are connected to a video cassette recorder and to a television monitor. Snake devices are generally limited to about 75 to 200 feet of pipe length.

The TSC maintains a database of all CCTV inspections they performed. The following information relating to embankment drain systems has been extracted from that database.

- *Common pipe material types.*—A variety of pipe materials has been used in the past to construct embankment drain systems. In some instances, combinations of pipe materials have been used. The most common pipe materials are (the numbers in parentheses indicate the percentage of use based solely on embankment drain systems inspected with CCTV):

  Clay tile (29%)
  HDPE (25%)
  CMP (22%)
  Concrete (16%)
  Polyvinyl chloride (PVC) (4%)
  Asbestos cement (3%)
  Iron (1%)

  Based on the embankment drain systems inspected, clay tile and CMP pipe were frequently used in older dams (1910 to about 1980), and HDPE pipe has been used in newer dams (1980 to present).

- *Common obstructions to CCTV inspection.*—Embankment drain systems can contain a variety of obstructions, which may limit the success of a CCTV inspection. These obstructions include (the numbers in parentheses indicate frequency of occurrence):

  Sediments, gravels, and rocks (40%)
  Sharp bends and tee sections (22%)
  Shape deformation and failure (11%)
  Roots (8%)
  Adverse invert slopes that prevent inspection (5%)

CCTV cable tether limitations (5%)
Joint offsets and separations (3%)
Pipe diameter constrictions (3%)
Other (3%)

The type and location of any obstruction encountered affect the overall success of the CCTV inspection. The typical range of completion for embankment drain inspection is (percentage is based on the total linear feet of embankment drain pipe inspected divided by the total linear feet of embankment drain system):

Inspection completion	Percentage of occurrence
0 to 24%	(49%)
25 to 49%	(15%)
50 to 74%	(13%)
75 to 100%	(23%)

As the data indicate, most embankment drain systems cannot be fully inspected.

- *Common defects observed.*—Some pipe materials are more prone to specific defects developing over time. The following summarizes specific defects observed within the most common pipe materials(the percentages shown are based on the number of embankment drain systems where a particular defect was found divided by the total number of embankment drain systems that contained the specific pipe material):

  - *Clay tile.*—Longitudinal and transverse cracking were observed in 24 percent of all embankment drain systems with clay tile pipes. Cracks ranged from hairline to extensive. Figure D-2 shows a clay tile pipe that has experienced extensive longitudinal cracking.

    Joint offsets and separations were observed in 67 percent of all embankment drain systems with clay tile pipes. Joint offsets and separations ranged from minor to extensive. Figure D-3 shows a clay tile pipe that has experienced extensive joint offsetting.

    Shape deformation and failure were observed in 24 percent of all clay tile pipes. Shape deformation ranged from minor to extensive. Figure D-4 shows a clay tile pipe experiencing a failure of the crown.

  - *HDPE.*—Shape deformation and failure was observed in 56 percent of all HDPE pipes. Shape deformation ranged from minor to extensive. Figure D-5 shows an HDPE pipe experiencing extensive shape

Figure D-2.—Extensive longitudinal cracking within a clay tile pipe.

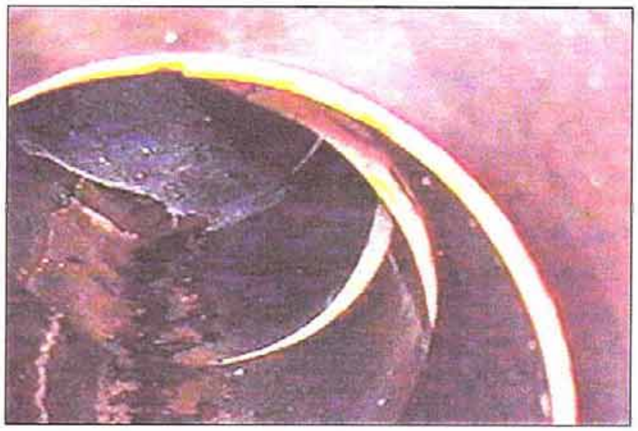


Figure D-3.—Extensive joint offsetting within a clay tile pipe.

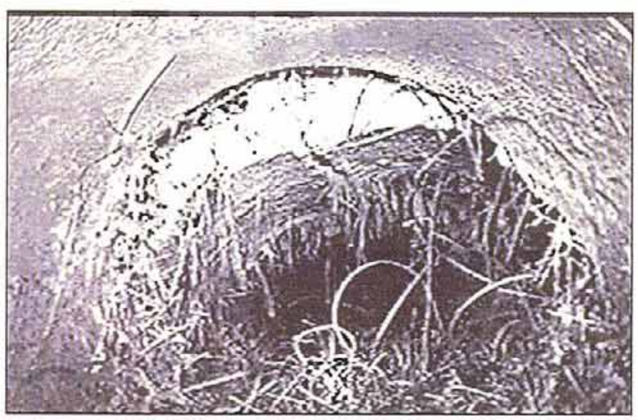


Figure D-4.—Clay tile pipe experiencing inward collapse of the crown.

Figure D-5.—HDPE pipe experiencing extensive shape deformation.

Figure D-6.—HDPE pipe experiencing failure at the crown. Materials surrounding the pipe have entered through the failure.

deformation. Figure D-6 shows an HDPE pipe that has experienced failure.

Joint offsets and separations were observed in 11 percent of all HDPE pipes. Joint offsets and separations ranged from minor to extensive. Figure D-7 shows an HDPE pipe joint that has experienced an extensive separation and has allowed materials surrounding the pipe to enter through the separated joint.

Figure D-7.—An HDPE pipe joint has experienced extensive separation. Materials surrounding the pipe have entered through the separated joint.

- *CMP.*—Deterioration was observed in 75 percent of all CMP pipes. Deterioration ranged from minor to extensive. Figure D-8 shows a CMP pipe that has experienced extensive deterioration.

  Some CMP pipes have the interior surfaces coated with asbestos bonded or bituminous coatings. Loss of surface coating due to delamination was observed in about 69 percent of all surface coated CMP pipes. Loss of surface coating ranged from minor to extensive. Figure D-9 shows a CMP pipe that has experienced extensive loss of surface coating due to delamination.

- *Concrete.*—Joint offsets and separations were observed in 58 percent of all concrete pipes. Joint offsets and separations ranged from minor to extensive. Figure D-10 shows a concrete pipe that has experienced extensive joint offset and separation at a bend in the pipe.

  Cracks were observed in 42 percent of all concrete pipes. Cracks ranged from hairline to extensive. Figure D-11 shows a concrete pipe that has experienced extensive transverse cracking.

- *Asbestos cement, PVC, and iron.*—A few cracks and joint offset/separation observations were noted within asbestos cement, PVC, and iron pipe. Figure D-12 shows a PVC pipe that has experienced extensive transverse cracking.

- *Plugging mechanisms.*—Plugging mechanisms can affect the performance of pipe perforations and slots and also the conveyance of collected seepage water. The most common plugging mechanisms encountered were (the percentages shown are based on the number of embankment drain systems

Figure D-8.—Extensive deterioration existing within a CMP pipe.

Figure D-9.—CMP pipe experiencing extensive loss of surface coating due to delamination.

Figure D-10.—Concrete pipe experiencing extensive joint offset and separation at a bend in the pipe.

Figure D-11.—Extensive transverse cracking within a concrete pipe.

Figure D-12.—PVC pipe experiencing extensive transverse cracking.

where a particular plugging mechanism was found divided by the total number of embankment drain systems with a plugging mechanism):

Sediments, gravels, and rocks (36%)
Biofouling (23%)
Mineral incrustation (23%)
Roots (18%)

Figures D-13 through D-16 are examples of embankment drain pipes which have experienced plugging due to sediments, bio-fouling, mineral incrustation, and roots, respectively.

- *Conclusions.—*

  - Clay tile pipe was frequently used in the construction of embankment drain systems. The common practice of laying clay tile pipe with open joints has allowed sediments, gravels, and rocks to enter into the embankment drain system. Entry of these materials has resulted in obstructions for inspection and plugging mechanisms. Clay tile pipes are also prone to joint offsets and separations, either from improper installation during construction, backfill loadings, or foundation conditions.

  - HDPE pipe has been used in many embankment drain systems constructed or modified after about 1980. HDPE pipe, while lightweight and easily handled and installed, has experienced a significant number of shape deformation and failure instances. Many of the HDPE pipe failures may be related to stress cracking. Stress cracking is a failure mechanism that develops over time at stresses less

Figure D-13.—Accumulation of sediments has resulted in plugging of the pipe.

Figure D-14.—Biofouling has resulted in plugging of the pipe.

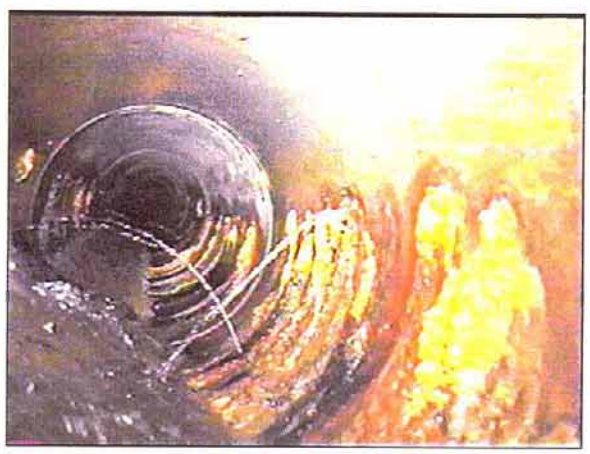


Figure D-15.—Mineral incrustation has resulted in plugging of a number of the pipe perforations.

Figure D-16.—Root growth has resulted in partially plugging the pipe.

than the yield strength. In the past, HDPE pipe resins have differed in the amount of stress crack resistance. Proper installation of HDPE pipe requires good compaction and quality control of the backfill to ensure good support under the haunches. If the pipe is not well supported by the backfill, the pipe will deflect excessively, and stresses will be concentrated at the crown, invert, or springline. These stress concentrations can lead to premature failure, especially if the pipe does not have sufficient stress crack resistance (SCR). Other failures could be the result of isolated point loads from construction loading, such as equipment crossings. When using HDPE for embankment drain applications, a preliminary CCTV inspection should be performed when 3 to 5 feet of backfill has been placed over the pipe. The purpose for this inspection would be to identify and repair any abnormalities, cracks, bulges, etc. early before construction is completed. Another CCTV inspection should be performed when the final backfill loading over the pipe is completed. CCTV inspection should be performed prior to the contractor pulling the torpedo-shaped plug or pig through the pipe and prior to any cleaning. The purpose for this inspection would be to identify any abnormalities, cracks, bulges, etc. that may have developed since the preliminary inspection. CCTV inspection could replace the need for pulling the plug or pig through the pipe.

- Most CMP pipes have experienced deterioration ranging from minor to extensive. The rate of deterioration varies, depending on chemical and physical properties of the soils and water and exposure to the environment. Where corrosion has occurred, it is a continuous and irreversible process. Interior surface coatings have been somewhat effective in extending the service life of CMP. However, most CMP pipe with surface coating has experienced some loss of coating from delamination.

- Bio-fouling and mineral incrustation are frequent plugging mechanisms that can affect the long term performance of pipe perforations and slots. In a few cases, cleaning using high pressure jet washing has been performed after identification during the initial CCTV inspection. Follow-up CCTV inspection has shown that the bio-fouling and mineral incrustation was generally removed from the interior surface. Some improvement of discharge from the embankment drain pipe is typically observed. However, no determination could be made as to the extent of the plugging mechanism remaining in the backfill materials surrounding the pipe.

For further information concerning the TSC's CCTV inspection program, contact Chuck Cooper (D-8130) at 303-445-3262.