APPENDIX 4 (CD)

OPERATION & MAINTENANCE PLAN

CITY OF ALBUQUERQUE

AMAFCA - Volumes 1-3

MAINTENANCE RESPONSIBILITIES

The Boca Negra Detention Dam and outfall pipe storm drain will be maintained and operated by AMAFCA. The City of Albuquerque (COA) will maintain the Boca Negra Arroyo outside of the Dam. AMAFCA and COA have maintenance programs with crews that maintain all drainage facilities on a routine schedule to ensure facilities are operating as intended.

AMAFCA has prepared an Operation and Maintenance Manual for AMAFCA Flood Control Dams (O&M Manual), which is included on the CD provided with the LOMR document. The manual describes the general plan of operation, inspection, and maintenance for AMAFCA owned and operated flood control dams in the greater Albuquerque area. The intent of this manual is to give all operation, inspection, and maintenance personnel uniform guidance and procedures to ensure proper operations and maintenance for all AMAFCA's flood control dams. In addition, this document provides a unified and consistent process for communications and coordination with other flood control agencies in the area. This manual was prepared in conformance with the Rules and Regulations of the New Mexico Office of the State Engineer Dam Safety Bureau (NMOSE-DSB). Information, data or modifications pertinent to NMOSE-DSB jurisdictional dams will be coordinated through the NMOSE-DSB. The O&M Manual consists of three volumes:

- Volume 1: General Information: consisting of general information and appendices concerning inspection and maintenance for all AMAFCA dams. A glossary of terms is provided in Appendix A of the O&M Manual to familiarize staff with terms relating to dams. Inspection guidance is included in Appendix B of the O&M Manual and a blank inspection form is provided in Appendix C of the O&M Manual. The inspection / maintenance forms are designed for easy revision.
- Volume 2: Individual Dam Characteristics: containing individual sections with specific information and dam modification history concerning each dam. Complete as-built plans are located on a disk included in Volume 2 and are on file at AMAFCA.
- Volume 3: Publications: with supporting publications.

CITY OF
Albuquerque

Federal Emergency Management Agency
Hazard Identification & Risk Assessment Division
500 C Street SW, Room 422
Washington, D.C. 20472

Community: City of Albuquerque,
New Mexico

Community No.: 350002

The City of Albuquerque, Public Works Department, Storm Drainage Maintenance Division, is responsible for the operation and maintenance of storm drainage systems in the City. The Storm Drainage Maintenance Division has 25 full-time employees, and is equipped to perform maintenance operations for all types of storm drainage facilities. Maintenance operations include sediment removal, pipe cleaning and flushing, pipeline, manhole, inlet repair and construction, concrete channel repair, and vegetation control.

Storm drainage maintenance activities are on-going throughout the year. Drainage system components are maintained per the following schedule:

System Component	***Inspection***	***Maintenance***
Pipes, Manholes, Inlets	Annual and following Complaints	Pipes, Manholes - Biannual Inlets - Annual
Channels, Arroyos	Annual	Annual, As Required
Detention Basins	Annual and following Complaints	Mowing - Annual Sediment Removal - As Req.

The Storm Drainage Maintenance Division is supervised by Mr. Glenn Jurgensen, Storm Drainage Superintendent.

Sincerely,

Larry A. Blair, P.E., Director
Public Works Department

OPERATION AND MAINTENANCE MANUAL
for
AMAFCA FLOOD CONTROL DAMS

located in
Bernalillo County, New Mexico

Revision 0
May 2011

Prepared by:
Albuquerque Metropolitan Arroyo Flood Control Authority
2600 Prospect Avenue NE
Albuquerque, NM 87107
(505) 884-2215

In Conjunction with:
URS Corporation
6501 Americas Parkway NE
Suite 900
Albuquerque NM 87110
(505)855-7500

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VOLUME 2: INDIVIDUAL DAM CHARACTERISTICS

*VOLUME 3: PUBLICATIONS

* Volume 3 is furnished on CD only to Office of the State Engineer, Dam Safety Bureau

I. INTRODUCTION AND DEFINITION OF GENERAL RESPONSIBILITIES

A. Introduction

This manual describes the general plan of operation, inspection, and maintenance, for Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) owned and operated flood control dams in the greater Albuquerque area. The intent of this manual is to give all operation, inspection, and maintenance personnel uniform guidance and procedures to ensure proper operations and maintenance for all AMAFCA's flood control dams. In addition, this document provides a unified and consistent process for communications and coordination with other flood control agencies in the area. This manual was prepared in conformance with the Rules and Regulations of the New Mexico Office of the State Engineer Dam Safety Bureau (NMOSE-DSB). Information, data or modifications pertinent to NMOSE-DSB jurisdictional dams will be coordinated through the NMOSE-DSB.

The manual is divided into three parts:

- Volume 1: General Information: consisting of general information and appendices concerning inspection and maintenance for all AMAFCA dams. A glossary of terms is provided in Appendix A to familiarize staff with terms relating to dams. Inspection guidance is included in Appendix B and a blank inspection form is provided in Appendix C. The inspection and maintenance forms are designed for easy revision. Complete as-built plans are located on a disk included in Volume 1 and are on file at AMAFCA.

- Volume 2: Individual Dam Characteristics: containing individual sections with specific information and dam modification history concerning each dam.

- Volume 3: Publications: with supporting publications.

B. Purpose and Intent

All AMAFCA dams are intended for flood control and the normal condition is dry with no permanently impounded water. Any storage allocations are temporary and are designed for downstream system capacity limitations. Proper operation and maintenance is essential for the continued viability and safety of each dam and its associated structures. Improper operation of any dam may result in increased risk to the dam and public and even dam failure. Poor maintenance can result in deterioration of the dam and its appurtenances, reduced life expectancy, and increased risk of dam failure. The following is included with AMAFCA's operation and maintenance program:

- Standard operating procedures
- Operating and maintenance procedures under emergency conditions
- Inspection guidelines and frequency
- Recordkeeping

This document is a living document and will be updated and changed as standards, technology, and regulations change, or if modifications are made to the dams. New or revised pages will be inserted and the date of revision will be listed on the bottom of the page. The existing page(s) will be marked with an X and left in the document in order to track the changes made. All revised pages in Volume I will be furnished to the NMOSE-DSB. Revisions to Volume II will be furnished to the NMOSE-DSB only on NMOSE-DSB jurisdictional dams.

C. Description of Flood Control Facilities

Flood control dams in the greater Albuquerque area are designed to control a 1% chance flood (100 year event), and emergency spillways are designed to pass the spillway design flood. Figure 1 is a Vicinity Map showing the location of all AMAFCA dams. Table 1 is an index keying all the dams to the Vicinity Map and to the Volume 2 tab numbers.

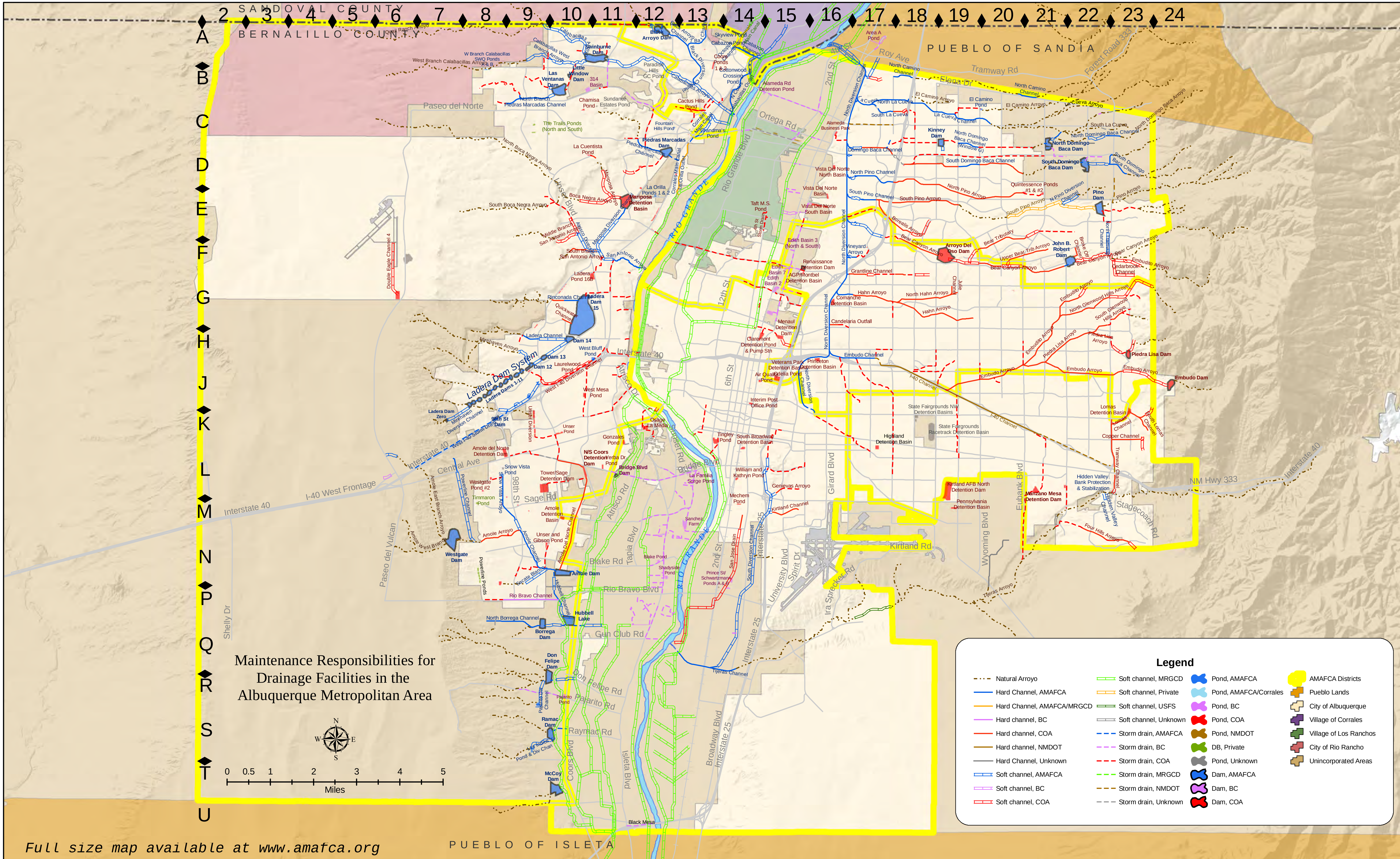
Table 1: AMAFCA Dam Index

Total Number of Dams	*Facility Name*	*Zone Atlas Page*	*Volume 2 Tab No.*
1	98th St Surge Pond Dam	K8	14*
2	Amole Arroyo SWQ Pond A	N9	15*
3	Amole Detention Basin	N10	6
4	Amole Sediment Basin #1	N9	16*
5	Amole Sediment Basin #2	N9	17*
6	Amole Sediment Basin #3	N9	18*
7	Black Arroyo Detention Dam	A12	19*
8	Borrega Dam	P9-P10	4
9	Cottonwood Crossings Pond	B14	20*
10	Don Felipe Dam	Q10-R10	3
11	El Camino Pond	B19-B20	21*
12	Fountain Hills Pond	C12	22*
13	Grandma's Pond	C13	23*
14	Hubbell Lake Detention Basin	P10	5
15	John B. Robert Dam	F21-F22	13
16	La Orilla Pond 1	D12	24*
17	La Orilla Pond 2	D12	25*
18	Ladera Dam 0	K7	26*
19	Ladera Dam 1	J8	27*
20	Ladera Dam 2	J8	28*
21	Ladera Dam 3	J8	29*
22	Ladera Dam 4	J8	30*
23	Ladera Dam 5	J8	31*
24	Ladera Dam 6	J8	32*
25	Ladera Dam 7	J8-J9	33*
26	Ladera Dam 8	J9	34*

Table 1: AMAFCA Dam Index

Total Number of Dams	*Facility Name*	*Zone Atlas Page*	*Volume 2 Tab No.*
27	Ladera Dam 9	J9	*35**
28	*Ladera Dam 10*	*J9*	*36**
29	*Ladera Dam 11*	*J9-H9*	*37**
30	*Ladera Dam 12*	*H9*	*38**
31	*Ladera Dam 13*	*H9-H10*	*39**
32	*Ladera Dam 14*	*H10*	*40**
33	*Ladera Golf Course - Dam 15*	*G10,G11,H10,H11*	*41**
34	*Las Ventanas Dam*	*B10*	*42**
35	*Little Window Dam*	*B10*	*43**
36	*Los Indios Pond*	*S9*	*44**
37	*Kinney Dam*	*C19*	*9*
38	McCoy Dam	T10	1
39	North Domingo Baca Dam	C21	10
40	North Pino Diversion Sediment Basin	D22	*45**
41	Octopus Pond	A14	*46**
42	Pajarito Diversion Sediment Basin	R9	*47**
43	Piedras Marcadas Dam	C12-D12	7
44	Pino Dam	E22	12
45	Raymac Dam	S10	2
46	Skyview Acres Pond	A14	*48**
47	Snow Vista Pond	L9	*49**
48	South Domingo Baca Dam	D22	11
49	Swinburne Dam	A10-A11	*50**
50	W Branch Calabacillas SWQ Pond A	B8	*51**
51	W Branch Calabacillas SWQ Pond B	B8	*52**
52	West Bluff Pond	H11	*53**
53	Westgate Dam	M7,M8,N7,N8	8

** To be added at a later date*


Maintenance Responsibilities for
Drainage Facilities in the
Albuquerque Metropolitan Area
SANDOVAL COUNTY
BERNALILLO COUNTY
PUEBLO OF SANDIA
PUEBLO OF ISLETA
RIO GRANDE
Legend
Natural Arroyo
Hard Channel, AMAFCA
Hard Channel, AMAFCA/MRGCD
Hard channel, BC
Hard channel, COA
Hard channel, NMDOT
Hard Channel, Unknown
Soft channel, AMAFCA
Soft channel, BC
Soft channel, COA
Soft channel, MRGCD
Soft channel, Private
Soft channel, USFS
Soft channel, Unknown
Storm drain, AMAFCA
Storm drain, BC
Storm drain, COA
Storm drain, MRGCD
Storm drain, NMDOT
Storm drain, Unknown
Pond, AMAFCA
Pond, AMAFCA/Corrales
Pond, BC
Pond, COA
Pond, NMDOT
DB, Private
Pond, Unknown
Dam, AMAFCA
Dam, BC
Dam, COA
AMAFCA Districts
Pueblo Lands
City of Albuquerque
Village of Corrales
Village of Los Ranchos
City of Rio Rancho
Unincorporated Areas
0 0.5 1 2 3 4 5
Miles
N
W E
S
Interstate 40
Interstate 25
Central Ave
Paseo del Norte
Coors Blvd
Rio Bravo Blvd
Tramway Rd
Kirtland Rd
Ladera Dam System
Full size map available at www.amafca.org

D. Access to Dams

Access to the dams for inspections and standard operations and maintenance is generally shown on the Zone Atlas pages in Volume 2. The AMAFCA maintenance crew is trained as to where to access the dams for standard operations and maintenance and given keys to the gates. If they have any questions as to where to access the dams they are instructed to ask the Maintenance Superintendent, Field Engineer, Real Estate Manager or GIS Technician. Access can also be seen on the AMAFCA Maintenance Map on the AMAFCA website at www.amafca.org.

In the event of an intense storm which denies access through normal means, the Emergency Action Plan will be invoked.

E. Key Personnel and Their Responsibilities

AMAFCA is responsible for routine and preventative maintenance, inspections, and operation of AMAFCA owned dams. Operations and maintenance actions along with the responsible personnel are shown in Table 2 below.

Specific duties for operation, inspection, maintenance and emergency operation or maintenance will be assigned according to the AMAFCA organization chart included in the AMAFCA Personnel Manual.

Only trained AMAFCA staff or crew, as shown in the Action/Responsibility Matrix in Table 2, may operate any of AMAFCA's dams. These people are collectively referred to in this document as the Operator. They are responsible for routine and annual inspections. More thorough inspections are required after intense storm events and, if possible, during the storm event. The dam operator is also responsible for monitoring conditions during high flow conditions. The operator will notify adjacent upstream and downstream operators about changes to the gate levels (where applicable) and may be required to change gate-operating levels. The dam operator will coordinate changes with owners of adjacent drainage facilities. The adjacent dam owners and their contact information are included in Table 5, in Section II.F. Adjacent drainage facility owners are shown on the map entitled *Drainage Facilities in the Albuquerque Metropolitan Area* available to all AMAFCA staff and crew. AMAFCA staff and crew that operate or maintain dams know the adjacent facility owners and are trained on possible impacts to adjacent facilities. If they have questions as to ownership they are instructed to ask the Maintenance Superintendent, Field Engineer, Real Estate Manager or GIS Technician. Adjacent ownership can also be found on the AMAFCA Maintenance Map at www.amafca.org.

Table 2: Action / Responsibility Matrix

Action	AMAFCA Personnel							Contractors		
	Board of Directors	Executive Engineer	Field Engineer	Maintenance Superintendent	Maintenance Crew	Drainage Development Storm Water Quality Engineers	Office Staff	Engineers	Surveyors	Maintenance
Maintenance Funding	P	S								
Inspection Funding	P	S								
Emergency Funding	S	P								
Emergency Procurement		P	S	S			P			
Media Communications	S	P	S	S		S	S			
Annual Inspections		S	P			S		S		
Quarterly Inspections		S	S	P	S	S	S			
Emergency Inspections		S	P	P	S	S	S	S		S
Post Operation Inspections		S	P	P	S	S	S			
5 Year Inspections		S	P			S		S		
5 Year Survey			P						S	
Level 1, 2 & 3 Maintenance			S	P	S					S
Level 4 & 5 Maintenance Design			P	S		S		S		
Level 4 & 5 Maintenance			P	S						S
Emergency Maintenance		S	P	P	P	S	S	S		S
Emergency Contacts		S	P	P	S	S	S			
Dam Operation		S	P	P	S	S				

P = Primary Responsibility, S = Secondary Responsibility

F. Documentation

All as-built drawings, construction documentation, inspection, maintenance, dam modifications, and any other documents relating to AMAFCA dams are kept in an Operations and Maintenance file kept for each individual dam in the AMAFCA office. An Inspection/Maintenance Log, a Dam Modification History, Dam Performance History and a copy of the latest inspection report are kept in Volume 2 for each dam in the applicable section.

II. OPERATION, INSPECTION, AND MAINTENANCE

Operation, inspection, and maintenance procedures are needed to ensure the public safety. Regular inspection is a requirement of proper maintenance. The operator can only reasonably maintain the dam in good working order with the support of an active inspection program. The following sections will be used to guide routine operation, inspection, maintenance, and emergency action.

A. Operational Procedures

1. General

All AMAFCA dams are operated for flood control. In early spring each year, gates will be serviced and operated. Dams with gates are noted in the individual dam sections in Volume 2 and any special instructions are noted on the Special Conditions Sheet also included in Volume 2. The maintenance crew is trained on proper operation and maintenance procedures on the gates.

None of the dams has yet achieved full capacity (first filling). When any dam is observed to approach its full capacity, the dam condition and water levels shall be closely monitored. All dams, upon their first filling, shall be closely monitored for seepage leaks around the conduit, in the downstream toe, and in the abutments. Upon first filling the Emergency Action Plan will be invoked.

2. Standard Operating Procedures

Gated Dams:
Gates on AMAFCA dam outlet structures are normally closed. In the event of rainfall, the AMAFCA Maintenance Supervisor or Field Engineer will notify downstream adjacent drainage facility owners. If there is no immediate need to open the gate they may agree to delay the opening to allow the downstream owner time to prepare for the flows. All downstream facilities are designed to take full flows from a fully opened gate. In the event the operator deems it necessary, gates will be fully opened prior to contacting the downstream owner. Gate operation wheels are located in the AMAFCA shop. Crew members are trained in their use. Crew and Staff are given keys to AMAFCA access control gates.

Non-gated Dams:
Non-gated AMACA dams are designed to meter the flow out of the dam with no specific operation necessary. The operator of the dam will monitor the outlet structure to ensure it is working properly. If the outlet structure is not working properly or in the event of potential flow through the emergency spillway, the Emergency Action Plan will be invoked.

3. General Surveillance Provisions

AMAFCA Field Engineer and Maintenance Supervisor have primary responsibility for surveillance of AMAFCA dams. Other crew, engineers, and staff may be used for surveillance depending on need. If the need arises, the adjacent drainage facilities can be found on the Vicinity Map and on the AMAFCA Maintenance Map found at www.amafca.org. Administrative and Emergency contact information is shown on Table 5 in Section II.F.

Early Warning System:

Currently, AMAFCA dams have no early warning systems. High water levels or increasing floodwater levels are not remotely monitored at this time. Doppler radar information is available for the greater Albuquerque area on time-delayed basis.

During a flood event the Dam Operator is responsible for initiating and maintaining constant communication with support staff assigned to dam locations. Communication will be by two way radio or cell phone. Changes (and anticipated changes) such as The rate of rise of the water level in the reservoir and changes in the inflow to the dam shall be noted and time stamped and immediately communicated to the AMAFCA Field Engineer. The AMAFCA Field Engineer will approve all dam operation changes throughout the event. Support personnel shall not change the operation of a flood control dam without approval of the AMAFCA Field Engineer, except in an emergency situation when communication is out and immediate action is required.

4. Response During Periods of Darkness

AMAFCA dams are not equipped with lights. Lights adjacent to dams and street lights may partially illuminate the dam and its appurtenances. AMAFCA has spotlight-equipped vehicles and inspectors are equipped with handheld flashlights.

5. Identification of Emergency

AMAFCA dams do not have automated flood warning systems. Seasonal weather conditions are monitored to help identify potential or developing floodwater conditions and to anticipate dam operations. Flood conditions are characterized by significant amounts of rain falling over relatively short periods of time. Reports of precipitation events in excess of 2-inches per hour are carefully evaluated and the affected facilities monitored. During flood events or high water events, AMAFCA personnel are trained and assigned to evaluate dam performance and report any and all abnormal conditions. In the event of an intense storm (as defined in the glossary) or other unusual event, each affected dam must be inspected for surface cracks, signs of movement, settlement, seepage, or erosion. If damage to the dam has, or is, occurring or the flood event is deemed an emergency, the Emergency Action Plan will be invoked. All dams when filling for the first time are to be monitored closely for any water flowing from around or in the vicinity of the conduit, the abutments, and the downstream toe. Performance of the spillway will also be monitored.

6. Emergency Repair Supplies and Resources

AMAFCA dam repair materials including sandbags, earth fill, and riprap are stockpiled at some dam locations for emergencies. Heavy equipment is available from AMAFCA or local area contractors. Other repair materials, such as concrete, flowable fill, etc., can be obtained from nearby commercial sources. Major repairs will be coordinated through the NMOSE-DSB as the situation and time allow.

7. Coordination or Floodwater Flows

Upstream flows may be regulated from the adjacent dams or drainage features. If a gate needs to be opened or an adjustment to flow made, the owner of the adjacent drainage facility must be notified. Adverse weather conditions may create rising water conditions. The Dam Operator is responsible for coordinating high water flows with the adjacent downstream dam operators.

B. Inspection

1. Inspection Frequency

Inspection is a necessary part of operation since early detection of gradual changes can reduce maintenance costs and identify minor problems before they become large, potentially dangerous and expensive repairs. Routine inspections provide a way to monitor the dams' performance. Only properly trained staff perform inspections. Inspection guidance is presented in Appendix B and AMAFCA Dam Inspection Report is shown in Appendix C. Table 3 summarizes inspection items and the frequency these inspections must be performed. The most recent Inspection and Maintenance Log can be found in Volume 2.

2. Inspection Safety

All Occupational Safety and Health Administration (OSHA) safety rules and regulations will be followed during inspections. Personal protective equipment will be used in accordance with OSHA rules and regulations and in accordance with the AMAFCA Safety and Health Policy and Job Hazard Analysis found on file at AMAFCA. Confined space entry will be performed only by individuals who are trained to do so.

Table 3: Dam Inspections

Items to Inspect	Frequency	Personnel
General Condition - after reservoir operations	Post Operation	AMAFCA
Embankment Seepage	Post Operation/Quarterly	AMAFCA
Reservoir Level	Post Operation/Quarterly	AMAFCA
Slides	Post Operation/Quarterly	AMAFCA
Spillway Cracks	Post Operation/Quarterly	AMAFCA
Debris in Primary Spillway	Post Operation/Quarterly	AMAFCA
Debris in Intake Structure	Post Operation/Quarterly	AMAFCA
Animal Burrows	Post Operation/Quarterly	AMAFCA
Woody Vegetation	Post Operation/Annual	AMAFCA
Riprap Protection	Post Operation/Annual	AMAFCA
Slope Erosion	Post Operation/Annual	AMAFCA
Vegetative Cover	Post Operation/Annual	AMAFCA
Embankment Condition	Post Operation/Annual	AMAFCA
Spillway Condition	Post Operation/Annual	AMAFCA
Gates	Post Operation/Annual	AMAFCA
Outlet Conduit	5 Years	AMAFCA
Dam Crest Surveys	5 Years	NM Professional Surveyor
Formal Engineering Inspection	5 Years	NM Professional Engineer

Quarterly inspections require little time to perform and provide insight on how the dam has performed under recent weather conditions. Annual inspections are designed to evaluate how the dam performed throughout the year and its current condition, covering items listed on the AMAFCA Dam Inspection Report, located in Appendix C. This inspection also evaluates and documents how the dam has changed from its original as-built condition. Detailed photo documentation provides a permanent record of the dam over time and allows for monitoring of any changing conditions. Repair and maintenance items are identified for correction. Annual inspections are normally performed in the late fall after the summer and fall rainy seasons. Annual inspections and good record keeping also allow for budgeting for any unusual or unexpected maintenance issues.

Maintenance identified as a result of any inspection is documented and performed using the following procedure. Maintenance issues are logged on the AMAFCA Inspection /Maintenance Report Form, found on page 6 of 6 on the AMAFCA Dam Inspection Form. A photograph is taken of each task required and annotated with a photo number and a brief description of the work to be accomplished. Once the photograph is printed, the location and nature of the work are noted on it as well. The AMAFCA Inspection /Maintenance Report Form, Page 6, is then given to the Maintenance Superintendent. Once a task is completed, the date of completion is noted after the appropriate annotation, and once all tasks are completed the form is signed by the Maintenance Superintendent and filed in the AMAFCA O & M File. A copy is not sent to the NMOSE-DSB unless Level 4 or 5 tasks, described in Section II.D and in the Glossary, are included.

Quarterly inspections are not documented in writing. In the event the quarterly inspection identifies the need for maintenance, the items will be documented using the annual inspection process. In addition if the quarterly inspection identifies something out of the ordinary, a formal written inspection will be done. Annual inspections are documented on the AMAFCA Dam Inspection/Maintenance Report form, located in Appendix C, and a copy is sent to the NMOSE-DSB on jurisdictional dams. Prior to performing an annual inspection, the inspector will review the AMAFCA O & M file and the most recent inspection report.

A five-year inspection by a New Mexico Professional Engineer is required by State Rules and Regulations. The AMAFCA Dam Inspection Report, located in Appendix C will be used to document the inspection. This inspection is coordinated through the NMOSE-DSB and includes the following items:

- Reviews of the most recent inspection and the pertinent information shown in Volume 2 specific to the dam
- Structure Integrity (concrete, up / downstream conditions)
- Dam Equipment Operation (gate operators, etc.)
- Outlet Conduits
- Emergency Spillway
- Earth Fill: slope, riprap, and abutment stability, seepage
- Vegetation

Post reservoir operation inspections must be made as soon as floodwater conditions have subsided. Dams are susceptible to damage during high flow conditions and during rapid drawdown of the floodwaters from the reservoir. Listed below are key elements to be inspected after storm flows have subsided:

- Vegetation: high flow damage
- Earthen Fill: slope, riprap, and abutment stability
- Cut or fill slopes within the reservoir area
- Erosion in the reservoir area and embankment slopes
- Seepage
- Gate Openings: deposited debris
- Plugging of Outlet Structures
- Deposition of Sediment
- Spillway and Emergency Spillway Condition
- Inlet and Outlet Channels

Repair and maintenance items will be identified during the inspection and will be logged on the AMAFCA Dam Inspection/Maintenance Report, located in Appendix C

Some conduit inspections and dam elevation surveys are performed as a separate inspection as funding and scheduling allow. Copies of those inspections will be kept in the AMAFCA O & M files and noted on the Inspection/Maintenance Log in Volume 2. The NMOSE-DSB will be furnished a copy of these inspections on jurisdictional dams.

3. Inspection Equipment

The Dam Owner / Operator and qualified inspection personnel must be adequately equipped for inspection. The following are recommended inspection related equipment items:

- Copy of site map and drawings of dam appurtenances, as needed
- Camera
- Hand pick
- Measuring tape
- Knives for prying cracks and removing materials
- Mirror
- Gloves
- Hard hat, when required
- Flashlight
- Hand Level
- Confined space entry equipment, when required
- Other personal protective equipment (PPE), where required
- Any other safety equipment required by OSHA or in the AMAFCA Safety and Health Policy or identified on AMAFCA Job Hazard Analysis Forms, found on file at AMAFCA.

C. Monitoring

Some of the dams are equipped with monitoring apparatus as shown in the individual sections describing each dam in Volume 2. Water surface elevations and rates of rise and fall can be measured by depth gages located as shown on the as-built plans. AMAFCA is in the process of installing depth gages on dams that do not have them, as funding and scheduling allow. Monuments to measure settlement are generally located on each dam, as shown in the as-built plans. Settlement monuments will be surveyed every 5 years. Surveys will be conducted to 0.01 foot accuracy. Settlements of over 0.2 feet are of concern and further investigation is warranted.

D. Maintenance

1. General

Flood control dams are built with earthen embankments, a principal spillway, and an emergency spillway. Specific information and selected as-built drawings for each dam can be found in Volume 2 in the section for that particular dam. Routine, annual, and post storm inspection results will dictate how often and to what degree maintenance, in addition to regular periodic maintenance, is required.

Repair work is separated into five maintenance levels depending on the severity of the work. Routine maintenance, Levels 1-3, will be performed by AMAFCA and the NMOSE-DSB will not be notified. Levels 4 or 5 which entail larger scale repairs or construction will be coordinated through the NMOSE-DSB, who will determine if a permit is required. The NMOSE-DSB will be notified by phone and in writing when Level 4 or 5 maintenance is being done. Level 5 work always requires NMOSE-DSB approval prior to commencement of work. Level 4 emergency work will not be delayed if the NMOSE-DSB cannot be reached. Level 4 work may invoke the EAP if necessary. AMAFCA will obtain a permit and adhere to all NMOSE-DSB conditions of approval. Records of all levels of maintenance are stored in AMAFCA's O & M file and can be accessed there.

Work corresponding to each level is shown below.

Level 1 – fencing, access control, trash and debris removal, grading of maintenance roads, encroachments

Level 2 – minor sealant repairs to concrete or minor concrete repairs

Level 3 – erosion less than 3 feet deep, rodent removal and repair of the remaining burrow, woody vegetation removal, adding or maintaining riprap, conduit inspection and cleaning, sediment removal

Level 4 – erosion 3 feet deep or greater, seepage repair, structural defects

Level 5 – major work requiring engineering investigation and possibly preparation of construction plans, modifications to the dam

AMAFCA personnel can repair most items, including all Level 1-3 items and possibly Levels 4 and 5. If larger repairs or specialized work are needed (Levels 4 and 5) then a qualified contractor will be hired. The owner's New Mexico licensed engineer will inspect all Level 4 and 5 repairs.

The following reference materials (current version) are used by AMAFCA in the maintenance and repair of their dams. These documents are available at the AMAFCA office.

- Current AMAFCA standards and details
- US Army Corps of Engineers Design Guidelines
- New Mexico Department of Transportation Standard Specifications for Highway and Bridges Construction
- City of Albuquerque Standard Specifications and Details
- N.M. Office of the State Engineer Dam Safety Bureau, Guidelines for Woody Vegetation Removal on Dams (Appendix D)
- FEMA 473 – Technical Manual for Dam Owners: Impacts of Animals on Earthen Dams (Appendix E)
- FEMA 534 – Technical Manual for Dam Owners: Impacts of Plants on Earthen Dams (Appendix F)
- US Bureau of Reclamation – Guide to Concrete Repair (Appendix G)
- Most recent NMOSE-DSB inspection report

2. Maintenance Frequency

Maintenance will be routinely performed. Periodic maintenance items are listed in Table 4 with the frequency shown. Frequency shown as "As Needed" may be a result of an inspection as called for in Section II.B, Inspection.

Table 4: Maintenance Items and Frequency

Item	Frequency
Exterminate or Remove Rodents	Quarterly or As Needed
Eliminate Rodent Burrows	Quarterly or As Needed
Remove Vegetation on dam slopes and along toes*	Annually or As Needed
Repair Erosion	Quarterly or As Needed
Clean Trash Rack or Outlet Structures	Quarterly or As Needed
Trash and Debris Removal	Quarterly or After Storm Events
Sediment Removal	Annually or As Needed
Repair Concrete	Quarterly or As Needed
Repair Mechanical Equipment	Quarterly or As Needed
Instrumentation	Quarterly or As Needed
Lubricate & Operate Gates and Valves	Annually, early Spring
Other Mechanical Equipment	Annually
Road Maintenance & Grading	Annually
Maintain Outlet Works Pertinent Features Free of Corrosion	Quarterly or As Needed
Riprap Maintenance	Annually

** Woody vegetation will be removed in accordance with the NMOSE-DSB Guidelines for Woody Vegetation Removal on Dams, found in Volume 3.*

3. Maintenance Safety

All OSHA safety rules and regulations will be followed during any maintenance activities. Personal protective equipment will be used in accordance with OSHA rules and regulations and in accordance with the AMAFCA Safety and Health Policy and Job Hazard Analysis found on file at AMAFCA. Confined space entry will be performed only by individuals who are trained to do so.

4. Maintenance Procedures and Documentation

All maintenance activities will be recorded along with the observations made by personnel. Routine observations provide the information needed to identify trends that could indicate that serious problems are developing. Identifying problems before they become serious is an important part of preventive maintenance. Maintenance activities that occur as a result of annual inspections will be documented on the AMAFCA Dam Inspection Report form, located in Appendix C. All maintenance records are kept in the AMAFCA O & M files.

All maintenance personnel shall be trained to recognize maintenance concerns and in the proper operation and maintenance of all aspects of dams under the control of AMAFCA. If any maintenance personnel are unclear as to proper maintenance and/or operation procedures or methods, they are to contact the Maintenance Superintendent or Field Engineer for proper instructions prior to the performance of any operation or maintenance function. Reference documents in Volume 3 will be used by the Maintenance Superintendent or the Field Engineer to determine correct procedures for maintenance or repair activities. In the event of more serious or uncommon repairs the Field Engineer will notify the Executive Engineer a contract engineer could be engaged for consultation or design.

5. Budget Considerations

Expendable items such as fencing, paint, lubrication, riprap materials, etc. will be used in the course of both preventive and routine maintenance. Riprap, geotextile fabric, and embankment fill materials will be stockpiled for both emergency and routine use. Other expendable items will be budgeted based on manufacturer's recommendations and owner's experience. Funds will be allocated for larger maintenance items and repairs, even though they may not always be predicted. AMAFCA maintains a Contingency Fund which reserves funds for unexpected, non-routine, and/or emergency maintenance and repairs. The Maintenance Superintendent and Field Engineer are authorized to commit the maintenance crew and equipment to perform routine and emergency operations. The Executive Engineer is authorized to commit up to $20,000 for labor, equipment, and materials. All amounts above that require approval of AMAFCA's Board of Directors.

E. As-Built Plans and Photo Documentation

As-built plans, photographs, detail construction dimensions, materials, and installed conditions must be monitored. Photos of selected features document how key features are being maintained.

F. Emergency Action Plan

Emergency Action Plans (EAPs) are being prepared in compliance with NMOSE-DSB Rules and Regulations for jurisdictional dams and, at a later date, for non-jurisdictional dams. AMAFCA has an ongoing process of preparing and updating EAPs for their dams. The purpose of the EAP is to provide the State, County, and City Emergency Managers and designated officials with specific guidelines and evacuation maps for emergency action in the event of a dam related emergency. The intent of this plan is primarily to protect the lives of citizens and secondarily to reduce property damage. Once an emergency condition is observed, AMAFCA will notify the appropriate Emergency Response Agencies as described in the notification flowcharts contained in the EAP and take action as described in the EAP.

Appropriate action/response is described in the EAP and will depend on whether Condition A or B exists, as noted below:

- Condition A: Failure of a dam is imminent or has occurred.
- Condition B: A potentially hazardous situation is developing at the dam.

Table 5 contains contact information for adjacent drainage facility owners and emergency response agencies.

Table 5: Adjacent Dam Owners & Emergency Response Agencies

Agency	Daytime Phone	After Hours Phone
Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA)	(505) 884-2215	(505) 362-1272 Kurt Wagener (505) 362-1268 Larry Trujillo (505) 362-0020 Jerry Lovato
City of Albuquerque o Police Department Dispatch o Fire Department o Emergency Management o City of Albuquerque Dept. of Municipal Development - Storm Drainage Design	 (505) 242-2677 (505) 833-7300 (505) 833-7381 (505) 768-2654	911
New Mexico Office of the State Engineer - Dam Safety Bureau	(505) 827-6122	(505) 476-9635 NMOEC 24-hour Duty Officer
Albuquerque Bernalillo County Water Utility Authority (ABCWUA)	(505) 842-9287	(505) 857-8250 - dispatch
Middle Rio Grande Conservancy District (MRGCD)	(505) 247-0234	(505) 247-0234 and receive directions
Bernalillo County o Sheriff's Office o Fire Department o Emergency Management o Public Works	 (505) 468-7100 (505) 468-1310 (505) 468-1307 (505) 848-1500	911 For all others see City/County Emergency Operations Plan
State of New Mexico o Department of Public Safety o Division of Emergency Management o New Mexico Department of Transportation	 (505) 827-3361 (505) 476-9600 (505) 827-5100	911
National Weather Service	(505) 243-0702	(888) 386-7637

III. SIGNS OF ABNORMAL CONDITIONS

As routine inspections are carried out, AMAFCA staff monitors the dams for any unusual or abnormal conditions. Upon notification by maintenance staff, AMAFCA Field Engineer, or other designated professional engineer, will determine if the following conditions exist. Abnormal conditions fall under Maintenance Levels 4 or 5, as defined in Section II.B.1 and in the Glossary. Detailed descriptions of the following abnormal conditions can be found in Appendix B in the Guidelines for Inspection of Existing Dams.

1. Excessive or Concentrated Seepage
1. Movements or Cracks in the Dams
2. Slumping, Sloughing, or Loss of Grade
3. Excessive Beaching or Erosion
4. Abnormal Instrument Readings
5. Concrete Problems
    a. Cracking
    b. Erosion and Cavitation
    c. Corrosion
    d. Movements
6. Abnormal Conditions in the Structural Steel / Reinforcing Steel
7. Abnormal Conditions with Mechanical Equipment
8. Landslides
9. Other Abnormal Conditions

APPENDIX A

GLOSSARY OF TERMS

ABUTMENT - That part of the natural ground against which the dam is constructed. The left and right abutments of dams are defined with the observer looking downstream.

ACRE-FOOT - A unit of volumetric measure that covers one acre to a depth of one foot. One acre-foot is equal to 43,560 cubic feet or 325,850 gallons.

AMAFCA – Albuquerque Metropolitan Arroyo Flood Control Authority.

APPURTENANT STRUCTURE - Ancillary features of a dam such as inlet structures, conduits, outlets, spillway, sluice gate, etc.

BERM - A nearly horizontal step (bench) in the sloping face of the dam.

BOIL - A disruption of the soil surface due to water discharging from below the surface. Eroded soil may be deposited in the form of a ring (miniature volcano) around the disruption.

BREACH - An opening through the dam that allows draining of the reservoir. A controlled breach is an intentionally constructed opening. An uncontrolled breach is an unintended failure of the dam.

CAVITATION – The rapid formation and collapse of pockets of vapor in a flowing liquid in regions of low pressure. Cavitation can occur in reservoir inlet or outlet works when high velocity water flow encounters discontinuities on the flow surface, causing the water to be lifted from the concrete surface, thus creating a negative pressure zone which may result in bubbles of water vapor. When the bubbles collapse against a concrete surface, a high pressure impact occurs and small particles of concrete may be removed. This forms another discontinuity, which can lead to cavitation damage. (US Bureau of Reclamation)

COLLECTOR DRAINS – A drainage system installed in the dam embankment to convey seepage flow safely away from the embankment.

CONDUIT - A closed channel (round pipe or rectangular box) that conveys water through, around, or under the dam.

CONTROL SECTION - A usually level segment in the profile of an open channel spillway above which water in the reservoir discharges through the spillway.

CREST OF DAM - See “top of dam”.

CROSS SECTION - A slice through the dam showing elevation vertically and direction of natural water flow horizontally from left to right. Or it may be a slice through a spillway showing elevation vertically and left and right sides of the spillway typically looking downstream.

DAM - A man-made barrier built across a watercourse or off-channel for the purpose of storage, control or diversion of water.

DAM FAILURE - The uncontrolled release of a dam’s impounded water.

DISCHARGE – Flow rate, typically measured in cubic feet per second or cubic meters per second.

DRAIN, TOE or FOUNDATION or BLANKET - A water collection system of sand and gravel and typically pipes along the downstream portion of the dam to collect seepage and convey it to a safe outlet.

DRAINAGE AREA (WATERSHED) - That geographic area on which all runoff flows into the dam. This may vary depending upon storm frequency.

DRAWDOWN - The lowering or releasing of the water level in a reservoir over time or the volume lowered or released over a particular period of time.

EMBANKMENT – A slope constructed of fill material, usually earth or rock, that is longer than it is high or the sloping side of a dam.

EMERGENCY - A condition that develops unexpectedly, endangers the structural integrity of the dam and/or downstream human life and property, and requires immediate action.

EMERGENCY ACTION PLAN (EAP) - A formal document identifying potential emergency conditions that may occur at the dam and specifying preplanned actions to minimize potential failure of the dam and to minimize failure consequences including loss of life, property damage, and environmental damages. The EAP includes an Evacuation Map.

EVACUATION MAP - A map showing the geographic area downstream of a dam to be evacuated if it is threatened by flooding caused by a breach of the dam or other large discharge. This map may also show planned evacuation routes.

FATIGUE STRESS – Progressive and localized stress that occurs when a material is subjected to repeated loading and unloading.

FEMA - Federal Emergency Management Agency, U.S. Department of Homeland Security.

FILTER - Layers of sand and gravel or a geotextile in a drain that allow seepage through an embankment to discharge into the drain without eroding the embankment soil.

FIRST FILLING – The initial filling of a dam with water to a specified design level, typically with flood control dams, this is up to or near the spillway crest.

FREEBOARD - The vertical distance between a design water surface elevation and the lowest point of the dam crest not including camber.

GATE, SLIDE or SLUICE or REGULATING - An operable, watertight valve to manage the discharge of water from the dam.

GROIN - The area along the intersection of the face of a dam and the abutment.

HAZARD - A situation that creates the potential for adverse consequences such as loss of life, property damage and environmental damages.

HEIGHT, DAM - The vertical distance as measured from the lowest natural ground surface elevation at the downstream toe of the structural fill of the dam to the crest of the dam.

HOMOGENEOUS EARTHFILL DAM - An embankment dam constructed of similar earth material throughout.

HYDROGRAPH, INFLOW or OUTFLOW or BREACH - A graphical representation of either the flow rate or flow depth at a specific point above or below the dam over time for a specific flood occurrence.

INSTRUMENTATION - An arrangement of devices installed into or near dams that provide measurements to evaluate the structural behavior and other performance parameters of the dam and appurtenant structures.

INTENSE STORM - A storm in which precipitation is greater than 2 inches per hour.

INUNDATION AREA or MAP - The geographic area downstream of the dam that would probably be flooded by a breach of the dam or other large discharge. The inundation map is used to develop the evacuation map.

LENGTH OF DAM - The length along the top of the dam between the abutments.

MAINTENANCE LEVEL 1 - Work consisting of fencing, access control, trash and debris removal, grading of maintenance, roads, encroachments. NMOSE-DSB notification is not required.

MAINTENANCE LEVEL 2 - Work consisting of minor sealant repairs to concrete or minor concrete repairs. NMOSE-DSB notification is not required.

MAINTENANCE LEVEL 3 - Work consisting of erosion less than 3-feet deep, rodent removal and repair of the remaining burrow, woody vegetation removal, adding or maintaining riprap, conduit inspection and cleaning, sediment removal. NMOSE-DSB notification is not required.

MAINTENANCE LEVEL 4 - Work consisting of erosion 3 feet deep or greater, seepage repair, structural defects. NMOSE-DSB coordination is required.

MAINTENANCE LEVEL 5 - Major work requiring engineering investigation and possibly preparation of construction plans and modifications to the dam. NMOSE-DSB coordination is required.

MRGCD – Middle Rio Grande Conservancy District.

NMOSE-DSB – New Mexico Office of the State Engineer Dam Safety Bureau.

NORMAL WATER LEVEL - For AMAFCA flood control dams, the normal condition is empty, therefore there is no normal water level.

NOTIFICATION - To immediately inform appropriate individuals, organizations, or agencies about a potentially emergency situation so they can initiate appropriate actions.

OPERATOR - The person or position in a company or organization, who is responsible for a dam's operation and surveillance.

OSHA – Occupational Safety and Health Administration.

OUTLET WORKS (PRINCIPAL SPILLWAY) - An appurtenant structure (gated or non-gated) that provides for controlled passage and release of water from the dam.

OVERSTRESS – Stresses greater than those allowed by the governing code.

OVERTOPPING – The rising of water to a level such that it would flow over the top of the dam or spillway.

PIPING - The progressive development of internal erosion by seepage flows, appearing downstream as a hole or seam discharging water that contains soil particles.

PROBABLE MAXIMUM PRECIPITATION (PMP) **or FLOOD (PMF) -** The theoretically greatest precipitation or resulting flood that is meteorologically feasible for a given duration over a specific drainage area at a particular geographical location.

RESERVOIR - The body of water impounded or potentially impounded by the dam.

RIPRAP - A layer of large stones, broken rock, precast blocks, or other suitable material, placed on an embankment, on a reservoir shore, or along a watercourse as protection against wave action, erosion, or scour. Very large riprap is sometimes referred to as armoring. Riprap may be dumped, wire-tied, or grouted.

RISK - A measure of the likelihood and severity of an adverse consequence.

ROTATIONAL SLIDE – A landslide in which the surface of the rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide (source - http://www.nationalatlas.gov/articles/geology/a_landslide.html)

SEEPAGE - The internal movement of water through the embankment, foundation, or abutments of the dam.

SLIDE - The disrupted movement of a mass of earth down a slope on the embankment or abutment of the dam or in the reservoir area.

SOIL CEMENT – A mix of native soil, portland cement, and water, compacted to a high density. It is commonly used for grade control structures and erosion control.

SPALLING – Spalling occurs when flakes of material are broken off a larger solid body. Typically with dam applications, it refers to concrete spalling and may have several causes including freeze/thaw cycles, poor finishing methods, or dissolved salts in water.

SPILLWAY (PRINCIPAL or EMERGENCY) - The appurtenant structure (gated or ungated) that provides the controlled conveyance of excess water through, over, or around the dam. The principal spillway conveys normal design flows (typically 100-year or less) from the reservoir and the emergency spillway conveys flow from the reservoir in excess of the design storm.

SPILLWAY CAPACITY - The maximum discharge the spillway can safely convey with the reservoir at the maximum design elevation.

SPILLWAY CREST - The lowest level at which reservoir water can flow into the spillway.

TAILWATER - The body of water immediately downstream of the outlet works and/or spillway at a specific point in time.

TOE OF DAM - The junction of the upstream or downstream slope (structural fill) of an embankment with the natural ground surface.

TOP OF DAM (CREST OF DAM) - The elevation of the uppermost surface of an embankment (structural fill), which can safely impound water behind the dam.

TRANSLATIONAL SLIDING – A landslide in which the landmass moves along a roughly planar surface with little rotation or backward tilting. (source - http://www.nationalatlas.gov/articles/geology/a_landslide.html)

WOODY VEGETATION – Plants that develop woody trunks, rootballs, and root systems that are not as large as trees but can cause undesirable root penetration in dams. (FEMA 534)

APPENDIX B:

GUIDELINES

FOR

INSPECTION OF EXISTING AMAFCA DAMS

TABLE OF CONTENTS

I. GUIDELINES FOR THE INSPECTION AND PREPARATION OF A REPORT ON THE CONDITION OF A DAM

The objective of the Dam Safety Program is to protect lives and property from the consequences of a dam failure or the improper release of impounded water. A primary means of achieving this goal is through the maintenance and periodic inspection of in-service dams.

The inspection program is intended to identify conditions that may adversely affect the safety and functionality of a dam and its appurtenant structures; to note the extent of deterioration as a basis for long term planning, periodic maintenance or immediate repair; to evaluate conformity with current design and construction practices; and to determine the appropriateness of the existing hazard classification. The professional engineer performing the inspection should, where appropriate, recommend subsequent investigations required to resolve uncertain conditions and corrective measures to enable the dam to continue to perform its intended functions.

A. Inspection Guidelines

The inspection guidelines are designed to assist AMAFCA Inspection Staff to better understand the requirements, responsibilities, and duties inherent with dam ownership and to assist the professional engineer by providing a consistent approach to dam inspection and in-service evaluation.

Several different types of dam inspections can be performed. Dams and appurtenances should be inspected regularly to identify conditions that may adversely affect the safety of a dam and its ability to perform intended functions. An inspection may include the periodic evaluation of the as-built dam elevations to determine if any settlement of the dam appurtenances has occurred.

II. SIGNS OF ABNORMAL CONDITIONS

Abnormal conditions fall under Maintenance Levels 4 or 5, as defined in Section II.D and in the Glossary. If these conditions are identified, the Maintenance Superintendent and Field Engineer will review the reference materials in Volume 3 to aid them in determining a course of action. Outside engineers and other resources may also be engaged to determine the course of action required for Level 4 and 5 maintenance or repair. The NMOSE-DSB will be notified as detailed in Section II.D on NMOSE-DSB jurisdictional dams.

A. Excessive or Concentrated Seepage

Seepage through the embankment under prolonged storage conditions is expected to be negligible in comparison to seepage through the foundation due to more permeable material, except at first fill along conduit and in abutments. Periodic visual inspections are required to detect any abnormal conditions such as excessive or concentrated seepage. Field personnel must visually inspect the area around the outlet conduit connection to outlet works, the downstream embankment toe, and abutment areas daily for seepage during periods of reservoir filling and on a 24-hour basis during flood stage. Areas of concentrated seepage must be critically observed for surface indications of sediment transport (piping) or erosion, change in quantity or concentration, and turbidity, or cloudiness of the water. The extent of saturated areas or ponding areas associated with concentrated seepage should be monitored.

A sign of abnormal seepage is when water emerges from a small area or single point. In this instance, evidence of sediment transport in the seepage areas is of particular concern. Emerging seepage must be inspected closely to determine if it is clear and free of any soil particles. The most critical sign of abnormal seepage is when water emerges from a small or single point with a build-up of soil particles forming a concentric mound called a sand boil. Chemical analysis of the seepage water and reservoir water may be required to determine whether piping or leaching is occurring. Sand boils must be observed, recorded and evaluated periodically for any change or trend that might indicate a worsening condition or long-term deterioration.

Some of the more apparent signs of abnormal seepage are whirlpools or vortices along the dam, or sinkhole or bog conditions on the downstream portion of the dam and toe. It is generally agreed that the properties of the water may be more significant than the absolute amount of water. Good records and proper analysis of these records are essential to the evaluation of the seepage along with the time line of significant occurrences, including precipitation data and pool elevations. It is important to gather as much information as possible about the seepage conditions in terms of location, extent, changes with time, seepage quantities, and characteristics (i.e., sediment transport, boils, loss of grade, etc.). Photographs will be used to document the conditions and provide a basis for evaluating changes.

B. Movements or Cracks in the Dams

Field personnel must observe and periodically inspect the embankment crest and slopes for movements or cracks in the dams. Specific inspections must be made after earthquakes and during periods of rapid pool filling or drawdown. Anticipated vertical movements are gradual. Abnormal conditions would be indicated by abrupt changes in the crest profile. Following an earthquake occurring at the project or sudden filling or drawdown, the crest should be inspected for cracks and displacement. Unusual movements may be detected through observation of the alignments of the crest station markers. Significant misalignment, tilting or displacement can be observed readily.

C. Slumping, Sloughing or Loss of Grade

As in the case of movements or cracks, specific inspections for slumping, sloughing or loss of grade must be made after an earthquake and during periods of rapid pool filling or drawdown. In addition, specific inspections should be made after severe or violent storms. Significant movement would appear in the form of bulges, depressions, or breaks in the embankment outer slopes. The top of the embankment may be the most vulnerable part during a strong earthquake.

D. Excessive Beaching or Erosion

Accepted methods and procedures for dumped rock placement may still result in varied in-place gradations and occasional reaches of smaller stone on the embankment slope.

These reaches are not distinguishable because slope dressing sometimes results in smaller rock on the surface only. During reservoir operations, waves can hit against areas of smaller sized stone, resulting in step-like benches. Smaller size stones move downslope to form a berm referred to as beaching, also known as segregation. The damage is usually minor (unless the wave action is severe and duration significant) and can be detected and corrected before serious damage develops.

Areas of concentrated surface flow not considered in design and construction but apparent during operations should be brought to the immediate attention of AMAFCA's Engineer for evaluation of corrective action. During a single violent storm, deep gullies can be eroded where flows tend to concentrate. Progressive caving at the head of such gullies (headward erosion or headcutting) can result in damaged slopes that are difficult and costly to repair. Headward erosion is of particular concern if it cuts into the crest of the dam.

E. Response to Abnormal Instrument Readings

A settlement of 0.2 feet will be considered an abnormal settlement of a dam survey monument. When an abnormal instrument reading is observed, it should first be verified. A check of any equipment used in making the original measurement should he performed. Once the condition is verified, determine if it is localized. Take other measurements in the general area noting changes in previous values or trends. Visually observe the area for signs of distress, wet or damp spots, loss of grade or bulging. Gather as much technical information as possible about the condition to aid in its analysis.

F. Concrete and Soil Cement

Distress in concrete and soil cement is manifested in a number of ways, including cracking, cavitation, scaling, erosion, disintegration, corrosion or chemical attack, distortion and misalignment. The seriousness of each of these depends upon how advanced the distress has become.

1. Cracking

Cracking is the process of breaking or splitting, usually without complete separation of the structure. Some cracking is expected, but sudden new cracks, a large number of cracks, significant seepage through the cracks, or cracking much wider than hairline ($1/64^{th}$ inch) are obvious indicators of distress in concrete. Cracking has many forms: pattern, random diagonal, longitudinal, and transverse. The causes of cracking are many, but usually can be related to structure overloading, expansion, shrinkage, and alkali-silica reactivity or other chemical reaction. The following is a list of various types of cracking and the possible causes.

- Pattern cracking begins as fine openings on concrete surfaces in a pattern. Pattern cracking with a whitish gel or other secretion in the cracks is the typical result of alkali-silica chemical reaction. Alkali-silica reactivity occurs between the aggregate and the alkali in the cement and can produce severe expansive forces in the concrete.
- Shrinkage cracking usually occurs in random fashion and is very common. It happens when the concrete is restrained, allowing tensile stress to build up and

exceed the tensile strength of the concrete. Shrinkage cracking usually takes place at regular intervals between joints in walls and slabs on-grade.

- Thermal expansive forces in concrete can result in cracking in areas of wide temperature variation, where movement of the concrete is completely restrained. This can result in buckling of the concrete.
- Cracking can occur due to overloading of a structure and will take place in areas where restraint and stresses are highest. Cracking due to overloading is frequently wider than the other types and occurs suddenly, causing more immediate concern. Examples may be found at the intersection of two walls, at an increases in size of a tunnel, at discontinuities (holes or penetrations), or at abrupt changes in slab or wall thickness.

Shrinkage, alkali-silica reaction, or other expansion cracking is generally either an inactive or slowly progressing problem and allows ample time for analysis.

Cracking of any type may lead to other serious problems, such as corrosion of steel reinforcement, water leakage in hydraulic structures, and even loss of structural integrity. Therefore, a cracking survey, monitors, or gages may be helpful in locating, marking, and identifying the cracks, and possibly identifying their cause. This survey also aids in determining if the cracking is progressive and in evaluating the future serviceability of the structure.

2. Erosion and Cavitation of Concrete

Erosion and cavitation of concrete due to the flow of water, or solids in water, is common in hydraulic structures. It is not expected anywhere except at the outlet conduit just downstream of the gate (where applicable). The seriousness of the problem depends upon the flow rate, particle load of the flow, and durability of the concrete.

- Moderate erosion is usually defined as the removal of the surface mortar of the concrete, exposing some coarse aggregate. Moderate erosion requires no action beyond monitoring.
- Serious erosion is defined as the actual removal of concrete well below the original surface, possibly exposing steel reinforcement. Because deterioration of this type is usually progressive, repairs should be done immediately.
- Cavitation causes erosion. Once a failure has started, depressions in the surface accelerate the damage to the concrete. Damage from cavitation is not common at water velocities below about 40 feet per second.

3. Corrosion

Chemical attack of concrete can occur from a number of agents and the effects are usually very obvious although the cause may not be. This type of distress is typically marked by simple disintegration of the concrete. It can occur in the presence of any number of chemicals in high concentration; for example, an odor of sulfur (hydrogen sulfide gas) in the conduit may be an indicator of sulfuric acid attack.

4. Movements

Deflection, distortion, or settlement of concrete structures, walls, beams, etc., beyond the small amounts expected after initial loading is considered serious and significant if on the order of 1/4 inch or more. Indications of these conditions are: leakage, separation, cracking, bulging, spalling, and/or misaligned joints (obvious vertical movement at the joint between a building and exterior walls).

The condition of joint filler material and the existence of vegetation or debris in the joint should also be checked. All of these conditions can be readily identified by a visual inspection.

In hydraulic structures, if the downstream side of a joint is higher than the upstream side, it can be particularly destructive during high-velocity flow. This condition can be detected by sliding a foot across the joint to determine if a small difference in elevation exists.

G. Structural Steel and Reinforcing Steel

Overloading from the gate and valve maintenance operations or missing bolts at the supports could cause distress in the control structures hangar beams. Distress can be detected by observing the beams and girders for misalignment, paint peeling, movement cracking, or missing bolts.

Corrosion of steel reinforcement can occur due to a number of agents. Typically, corrosion results from simple exposure to air and moisture. It can become serious if not repaired or is allowed to expand beyond small areas. Exposed rusted steel, concrete marked by reddish or dark gray stains, and bulging or spalling of the concrete in lines parallel to the reinforcement indicates corrosion of reinforcement.

Steel can also be subject to corrosion and deterioration where it is subjected to chemical action of water, bird droppings, human, or animal waste concentrations. Concentration of stress might be produced in areas where there is an abrupt change in the metal size or configuration. Fatigue stress can occur when members are subjected to vibration or movement. Overstress can be evidenced by excessive deflection under passage of heavy loads. Bracing members should be securely fastened.

Cavitation at the gates, valves and steel liners can occur under certain conditions. Just as in concrete, irregularities in the steel or high heads can cause bubbles in low-pressure areas to collapse with great impacting force as they enter areas of high pressure. Holes and/or pits formed in the surface of the steel indicate cavitation while a smooth, worn appearance points to abrasion.

H. Mechanical Equipment

Malfunctioning of mechanical equipment may result from displacement of supporting structural elements, corroded or loose parts, misalignment of parts, binding due to infrequent operation, insufficient lubrication, or improper operation. Unusual noises from conduit air vents should be noted, as this could indicate irregular flows caused by a damaged gate or conduit.

The capability of lowering the reservoir, should structural distress dictate, depends upon the outlet works and operable mechanical equipment. Procedures have been developed for avoiding abnormal conditions and problems with mechanical equipment to ensure operability of the outlet works. Effective defenses against problems with mechanical equipment include:

- regular examinations
- preventive maintenance on a regular schedule and including lubrication
- repair of deficiencies
- prominently posted, clear and concise operating instructions
- periodic exercising or testing of equipment
- a reliable alternate power source

During each pre-flood, post operation and periodic inspection, all equipment such as gates and valves, emergency power generator, and ancillary equipment must be inspected and operated to ensure that they are in good operating condition.

Cavitation of the gates, valves and steel conduits can occur under certain conditions. Just as in concrete, irregularities in the steel or high heads can cause bubbles that are formed in the areas of low pressure. Cavitation is recognized from the holes or pits formed in the surface of the steel.

I. Landslides

The cut slopes along the backslopes of reservoirs should be free of sloughs, slides and debris. Slide problems usually occur during periods of excessive precipitation and surface runoff and or rapid drawdown of the reservoir. Shallow translational slides typically occur in granular material with little or no cohesion and deep rotational slides typically occur in cohesive material. Deep rotational slides engage more material and therefore have the highest potential for creating significant damage. Surface slides do not result in significant mass movement, however with time these slides have the potential of progressively engaging more material and becoming larger. Consequently, surface slides require remedial actions to prevent progressive movement.

Natural or constructed fill or cut slopes should be examined for the presence of cracking, slumping, or other signs of movement. Cracks are usually symptoms of distress. Cracks in shotcrete surfaces that are not random in pattern (non-shrinkage cracking) indicate movement of the slope. Water can enter the slope through cracks and increase the driving force on the slope and reduce the resisting strength of the soil. Therefore, to minimize the potential for slides, ensure that slopes drain properly so that water cannot collect in them or cause erosional gullies. Ensure that all drainage devices such as horizontal drains and ditches are unobstructed and not damaged. If practical, cracks should be covered or sealed to prevent water from entering. Emergency or short-term remedial actions would consist of covering the cracks with anchored (i.e., sand bags, etc.) plastic sheeting.

In maintaining roads, care should be taken not to alter drainage or undercut slopes. Cracks in roads due to slope movement should be sealed to prevent water from entering the slope. Keep plastic sheeting and sandbags readily available. If possible, also keep a stockpile of clayey soil readily available.

The perimeter of the reservoirs should be checked for slides following periods of heavy precipitation and large volumes of runoff, extreme reservoir water level fluctuations, and earthquakes. Close surveillance should be maintained until there is assurance that potential landslides do not present a problem to any reservoir operation. Landslides can often be detected by the bare surface between the top of the slide (head) and the original ground surface (crown), bulges at the toe, or leaning trees.

J. Other Abnormal Conditions

The trash rack, outlet conduit, spillway channel and exit structures should be checked regularly and after storm events to keep them free from sediment and debris. Debris can cause restriction of the flow and erosion of the concrete surfaces. Slope protection should be examined to determine if it is performing satisfactorily. Collector drains and slope drain holes should be checked to determine that they are open and free of obstructions that may impair their function. A change of flow rate may be an indication of a developing problem. Water seeping through joints may indicate defective collector drains. Collector drain discharge should be examined routinely to ensure the discharge water is not carrying material. Drain hole efficiency may decrease with time due to biological growth, leaching, and the formation of chemical deposits. When obstructed, drain holes should be cleaned or new drain holes installed.

Pre-flood season inspections should include an inspection of the upstream conveyance system for the purpose of identifying any significant trash or debris accumulations that have been deposited in a location from which they can be washed into the reservoir and cause a blockage of the spillways.

APPENDIX C:

AMAFCA DAM INSPECTION REPORT

AMAFCA DAM INSPECTION REPORT

Project ____

Date ____________________ **Inspector(s)** _______________________________

AMAFCA O&M File # ________________ **OSE File #** _________________________

PROJECT CONDITION:

A. General – Will project operate as intended during a heavy storm? Yes _____ No _____

If in doubt, explain:

____

____

B. Embankment and Abutments

1. Surface Cracks____
2. Movement or cracking at or beyond toe__________________________________
3. Soughing of slopes____
4. Vertical alignment of crest (settlement)__________________________________
5. Horizontal alignment of crest (movement)________________________________
6. Junction of embankment and abutment__________________________________
7. Junction of spillway and dam____
8. Seepage____
9. Condition of gutters, internal drains____________________________________
10. Traffic damage____
11. Erosion ____
12. Drains, Erosion control devices_______________________________________
13. Vegetation____

14. Animal Burrows____

15. Ant activities____

C. Reservoir Area

1. Adequate capacity (free of sediment)__________________________________

2. Free of large debris____

3. Incoming arroyo/channel condition____________________________________

D. Principal Spillway

1. Intake structure

   General condition____

   Clear of debris?____

2. Conduit

   General condition____

   Junction with intake structure______________________________________

   Debris____

   Sediment____

   Condition of joints____

   Alignment (horizontal)____

   (vertical)____

   Circularity____

Junction with outlet structure____

Seepage____

3. Gates and Valves

General condition____

Operable?____

4. Outlet Structure

General condition____

Debris____

5. Outlet Channel

General Condition____

Wire enclosed riprap

Transition from outlet structure____

Condition of wire____

Condition of tie wires____

Condition of riprap____

Evidence of undermining____

Erosion control structures

Type____

Condition____

Head cutting

Distance from structure____

Description (depth, width, etc.)____

6. Emergency Spillway

General condition____

Grade control/erosion checks____

Erosion____

Debris/Blockages____

Condition of concrete, riprap, gabions, wire-enclosed rock ____________________

____

____

____

____

7. Other____

E. Project Safety

Guard Rail____

Delineators ____

Fence and Gates____

Warning Signs____

Barriers/Barricades____

Manhole Covers____

F. Right Of Way

Unauthorized use of project lands____

Property Signs:

Missing ____

Damaged____

Monuments____

Maintenance Roads____

Encroachments____

AMAFCA Dam Inspection/Maintenance Report Form

Facility ______________________________________ Date ________________________

Inspector's initials _________________________ AMAFCA O&M File # _______________

Required Maintenance/Repairs

Urgent (Level 4 or 5)

Picture Number	*Work to be Accomplished*	*Date Completed*

Routine (Level 1, 2, or 3)

Picture Number	*Work to be Accomplished*	*Date Completed*

_________________________ Date Items Completed

_____________________________________ Signature

Boca Negra Detention Dam

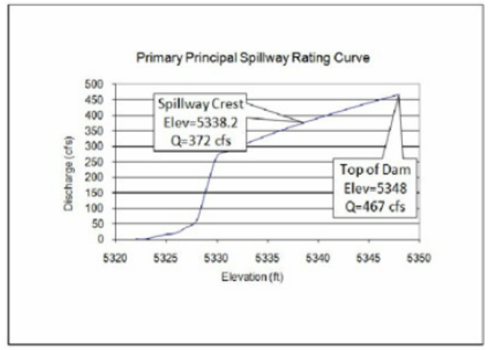
Operation, Maintenance, Repair, Replacement, &
Rehabilitation Manual

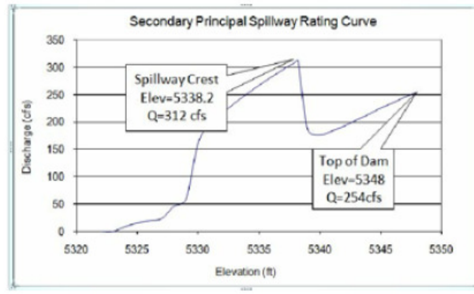
Volume 2 – Book 2, Tab 56

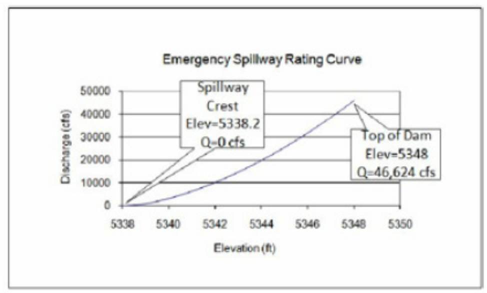
BOCA NEGRA DETENTION DAM CHARACTERISTICS

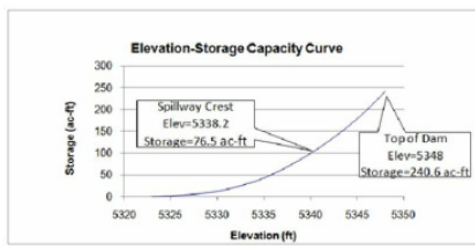
OSE File Number D-695 | National Dam ID Number NM00698

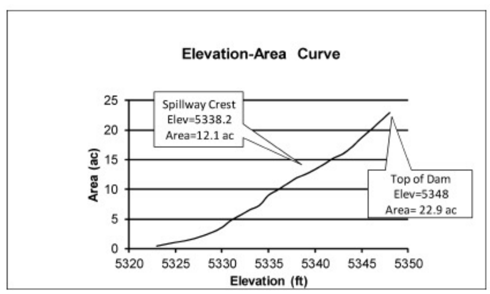
NAME OF DAM		BOCA NEGRA DETENTION DAM
TYPE OF DAM (MATERIAL)		HOMOGENEOUS EARTH EMBANKMENT
HAZARD POTENTIAL CLASSIFICATION		HIGH
MAX. HEIGHT ABOVE DOWNSTREAM TOE (FT)		26
MAX. LENGTH (FT)		3560
CREST WIDTH (FT)		17
SLOPE OF UPSTREAM FACE xH:1V		3 TO 1
SLOPE OF DOWNSTREAM FACE xH:1V		2.5 TO 1 & 3 TO 1
ELEVATION OF DAM CREST (FT)		5348
ELEVATION OF EMERGENCY SPILLWAY CREST (FT)		5338.2
EMERGENCY SPILLWAY WIDTH (FT)		419
1. PRIMARY PRINCIPAL SPILLWAY CONDUIT LENGTH (FT)		143
2. SECONDARY PRINCIPAL SPILLWAY CONDUIT LENGTH (FT)		145
1. UPSTREAM INVERT PRIMARY PRINCIPAL SPILLWAY (FT)		5318
2. UPSTREAM INVERT SECONDARY PRINCIPAL SPILLWAY (FT)		5323
1. DOWNSTREAM INVERT PRIMARY PRINCIPAL SPILLWAY (FT)		5311.9
2. DOWNSTREAM INVERT SECONDARY PRINCIPAL SPILLWAY (FT)		5321.8
FREEBOARD (FT)		10
RESIDUAL FREEBOARD (FT)		1.1
MAX EMERGENCY SPILLWAY DISCHARGE AT TOP OF DAM (CFS)		45903
1. PRIMARY PRINCIPAL SPILLWAY MATERIAL AND SIZE		48" x 48" CBC
2. SECONDARY PRINCIPAL SPILLWAY MATERIAL AND SIZE		48" x 48" CBC
1. MAX PRIMARY PRINCIPAL SPILLWAY DISCHARGE AT TOP OF DAM (CFS)		467
2. MAX SECONDARY PRINCIPAL SPILLWAY DISCHARGE AT TOP OF DAM (CFS)		254
1. LOCATION OF PRIMARY PRINCIPAL SPILLWAY		31.03722°N 107.66167°W
2. LOCATION OF SECONDARY PRINCIPAL SPILLWAY		31.03778°N 107.66167°W







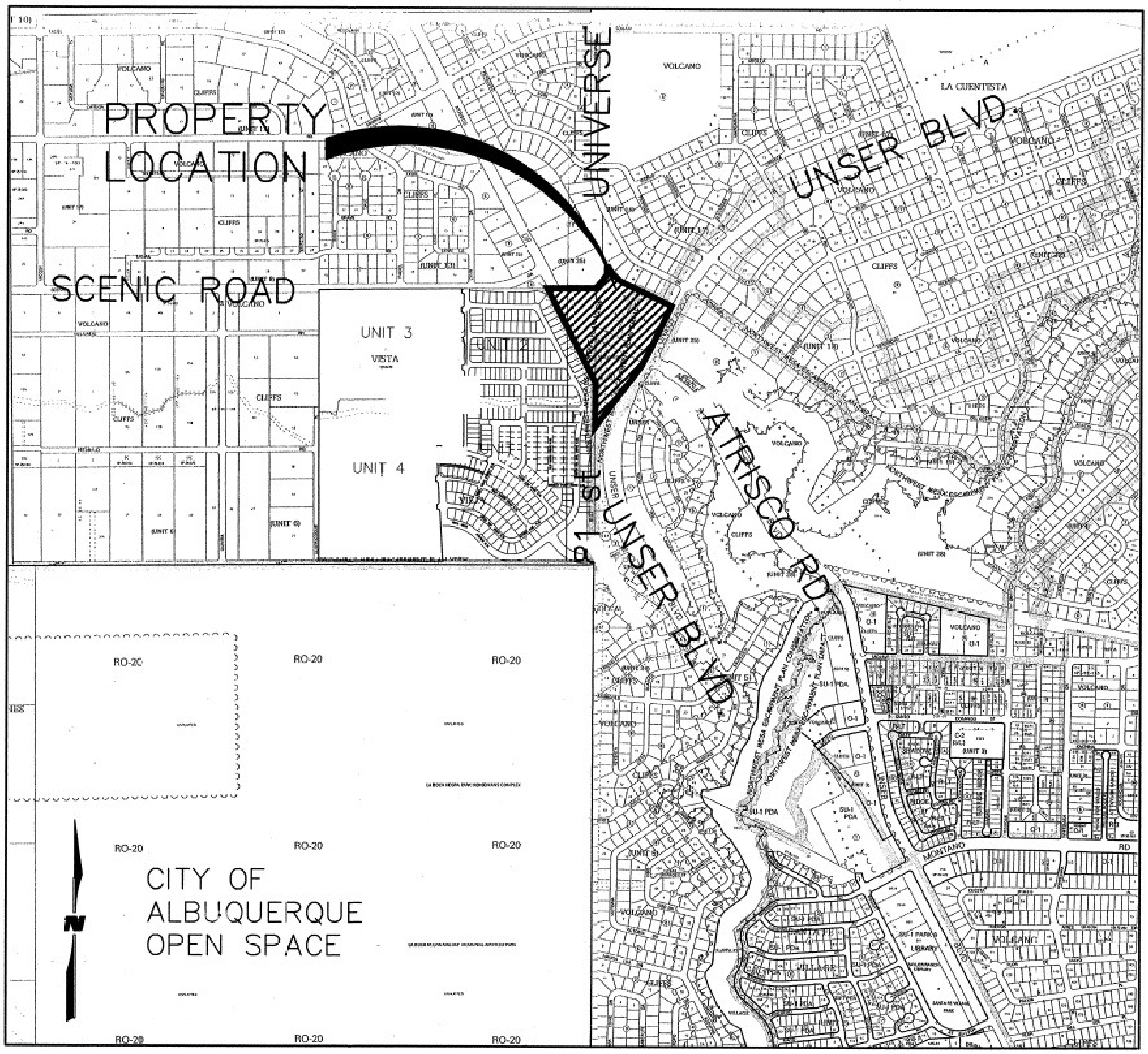




BOCA NEGRA DETENTION DAM CHARACTERISTICS			
ELEVATION (ft)	DISCHARGE (CFS)	STORAGE (AC–FT)	SURFACE AREA (ACRES)
5318=4' X 4' CBC (PRIMARY) SPILLWAY INV			
5319	0	0	0
5320	0	0	0
5321	0	0	0
5322	0	0	0
5323=4' X 4' CBC (SECONDARY) SPILLWAY INV	0	0	0.5
5324	18	0.9	0.8
5325	31	1.8	1.1
5326	40	3.0	1.3
5327	62	4.5	1.7
5328	106	6.5	2.2
5329	226	9.0	2.8
5330	430	12.2	3.6
5331	479	16.4	4.8
5332	513	21.6	5.7
5333	545	27.7	6.6
5334	574	34.7	7.3
5335	602	42.8	9.0
5336	629	52.3	9.9
5337	655	62.8	10.9
5337.94 = 100 YR FUTURE CONDITION	677	73.5	11.6
5337.98 = 100 YR INTERIM CONDITION	678	74.0	11.9
5338	679	74.2	11.9
5338.2=EMERGENCY SPILLWAY CREST ELEVATION	684	76.5	12.1
5339	1,438	86.3	12.6
5340	3,699	99.3	13.4
5341	6,830	113.1	14.3
5342	10,683	127.9	15.3
5343	15,192	143.6	16.0
5344	20,320	160.2	17.2
5345	26,006	178.2	18.7
5346	32,315	197.6	20.1
5347	39,208	218.4	21.5
5348=TOP OF DAM	46,624	240.6	22.9

BOCA NEGRA DETENTION DAM

BOCA NEGRA
DETENTION DAM
ZONE ATLAS MAP



VICINITY MAP

ZONE ATLAS MAP NO. D- 9/10

Boca Negra Detention Dam

Special Conditions

1. City of Albuquerque Parks and Recreation maintains the shared use path, 3ft adjacent to trail.
2. Two existing gas lines exist along the south side of the dam (20” &12”). They are covered under a reciprocal encroachment agreement.
3. Overhead and underground electrical lines, as well as a substation, exist in the dam. They are covered by a reciprocal encroachment agreement.
4. There are two water lines in the dam (16” & 12”). They are covered by a reciprocal encroachment agreement.

BOCA NEGRA DETENTION DAM
PRIMARY ACCESS MAP

Boca Negra Detention Dam Modification History

Date	Modification	Entry Made By	Comments / Notes

Boca Negra Detention Dam Performance History

Date	Water Depth	Formal Inspection Required?		Action Required	Entry Made By	Comments / Notes
		Y	N			

Boca Negra Detention Dam

Inspection/Maintenance Log

Date of Inspection	Is Maintenance Required?	Maintenance Level	Comment

GUIDELINES FOR WOODY VEGETATION REMOVAL ON DAMS[1]

The guidelines for woody vegetation removal on dams are general guidelines and proper evaluation of the dam's geometry, woody vegetation species and other field conditions may be required before implementing these guidelines.

STORAGE DAMS

ZONE	DESCRIPTION	TRUNK DIAMETER (Inches)	TREATMENT
1*	Upstream slope	All	A
2	Crest	< 12	B
		≥ 12	A
3	Upper third of the downstream slope	< 8	B
		≥ 8	A
4*	Middle third of the downstream slope	< 6	B
		≥ 6	A & C
5*	Lower third of the downstream slope and downstream area for a distance of half the dam height	< 4	B
		≥ 4	A & C

* Lower the reservoir to a safe level, as determined by a professional engineer, before the repairs begin.

Treatment A:

1. Cut the woody vegetation approximately two feet above ground level leaving a prominent stump for use in the rootball extraction process;
2. Remove the stump and rootball by pulling the stump or extracting with a backhoe after loosening the rootball by pulling on the stump from different locations;
3. Clean the rootball cavity to remove loose soil and the remaining root system (root systems > ½ inch) by excavating the rootball cavity with maximum 1:1 (horizontal to vertical) side slopes and a horizontal bottom; and
4. Backfill the excavation with well-compacted soil placed in relatively thin lifts not greater than about 8 inches in loose lift thickness. Compaction typically requires the use of manually operated compaction equipment or compaction equipment attached to a backhoe. Backfill should consist of appropriate fill material and should be compacted to a minimum of 95% of the maximum dry density of the fill soil as determined by the Standard Proctor compaction test (ASTM D-698); and
5. For upstream slopes include a slope protection system to reduce the potential for wave and surface runoff erosion. For downstream slopes all disturbed areas shall be protected by seeding or mulching.

Treatment B:

1. Cut the woody vegetation stump flush with the ground;
2. Regularly treat the stump with a protective coating similar to polyurethane that will prolong the decay process.

Treatment C:

If water is encountered in the rootball cavity consultation with a professional engineer regarding the need for a filter drain system is required. A professional engineer must supervise the construction repair. Office of the State Engineer Dam Safety Bureau approval of the filter drain system design and installation is required.

DETENTION DAMS

For dams with no permanent storage, implement Storage Dams Zone 1 guidelines for the upstream slope and Zone 2 guidelines for the crest and entire downstream slope. Also implement Zone 2 guidelines for a distance 20 feet from the toe for dams < 40 feet in height and for a distance 25 feet from the toe for dams $\geq$ 40 feet in height.

MISCELLANEOUS AREAS OF DAMS[2]

Maintain 25-foot clearance zone beyond groins and adjacent to all concrete structures.

Maintain 15-foot clearance zone on each side of open channels, pipe conveyance systems and drains (especially perforated pipes).

1 Adapted from Marks, Dan B.; Tschantz, Bruce A. and Woodward, David K. *Plant and Animal Penetrations of Earthen Dams.* 2001 ASDSO Technical Seminar

2 Bureau of Reclamation (USBR). *Water Operation and Maintenance.* Bulletin No. 150, 1989.

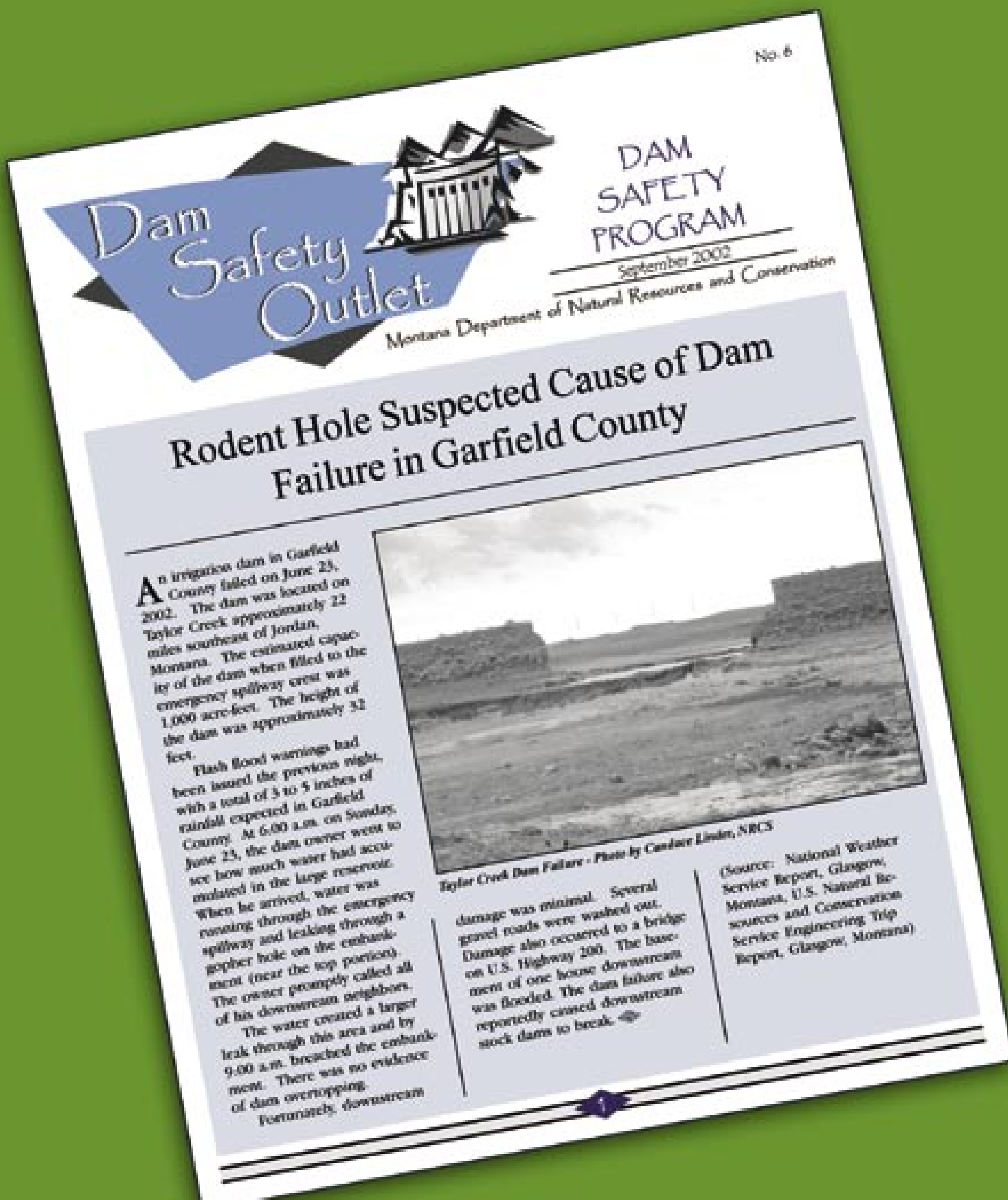
Technical Manual for Dam Owners

Impacts of Animals on Earthen Dams

FEMA 473 / September 2005

FEMA

Twenty-five states across the U.S. can write headlines of dam failure caused by nuisance wildlife intrusions, and many dam owners find the struggle to adequately manage nuisance wildlife at their dams a never-ending story. The Federal Emergency Management Agency (FEMA) has funded the development of this manual with the understanding that safe dam operation includes comprehensive, state-of-practice guidance on timely inspection and observation of wildlife damages, accurate wildlife identification and mitigation, and appropriate dam design, repair, and preventive measures. It is hoped that the information and methods contained in this manual will compose the core of dam management routines practiced by dam specialists across the country. Armed with education and diligence, dam specialists can prevent animal intrusion dam failure from becoming headline news.


No. 6

Dam Safety Outlet

DAM SAFETY PROGRAM

September 2002

Montana Department of Natural Resources and Conservation

Rodent Hole Suspected Cause of Dam Failure in Garfield County

An irrigation dam in Garfield County failed on June 23, 2002. The dam was located on Taylor Creek approximately 22 miles southeast of Jordan, Montana. The estimated capacity of the dam when filled to the emergency spillway crest was 1,000 acre-feet. The height of the dam was approximately 32 feet.

Flash flood warnings had been issued the previous night, with a total of 3 to 5 inches of rainfall expected in Garfield County. At 6:00 a.m. on Sunday, June 23, the dam owner went to see how much water had accumulated in the large reservoir. When he arrived, water was running through the emergency spillway and leaking through a gopher hole on the embankment (near the top portion). The owner promptly called all of his downstream neighbors.

The water created a larger leak through this area and by 9:00 a.m. breached the embankment. There was no evidence of dam overtopping.

Fortunately, downstream damage was minimal. Several gravel roads were washed out. Damage also occurred to a bridge on U.S. Highway 200. The basement of one house downstream was flooded. The dam failure also reportedly caused downstream stock dams to break.

Taylor Creek Dam Failure - Photo by Candace Linden, NRCS

(Source: National Weather Service Report, Glasgow, Montana, U.S. Natural Resources and Conservation Service Engineering Trip Report, Glasgow, Montana)

1

Technical Manual for Dam Owners

Impacts of Animals on Earthen Dams

FEMA

Table of Contents

1.0 Introduction and Purpose of Manual

1.1 Background

In 1999, the Federal Emergency Management Agency (FEMA) and the Association of State Dam Safety Officials (ASDSO) jointly conducted research and a workshop to shed light on the national problem of animal intrusion damage to earthen dams and the resulting safety issues. The FEMA/ASDSO survey and workshop united dam owners, engineers, state and federal regulators, wildlife managers, foresters, and academia to form an educated and experienced front against the growing problem of earthen dam damage and failures due to animal intrusion. The information generated by roundtable discussions and survey answers indicates that while most states recognize animal intrusion as a problem, only a handful know of guidance on dams and wildlife management practices available to the dam professionals and owners. Based on input from the dam communities, FEMA/ASDSO's mission to develop a guidance manual on the proper management of nuisance wildlife in the earthen dam environment became clear.

To determine the information needs of the dam community—and therefore the most appropriate focus of this manual—FEMA/ASDSO issued a survey in 1999 and used the survey input from the 48 state dam safety officials representatives and 11 federal agencies representing the Interagency Committee on Dam Safety (ICODS). Additionally, a second survey was issued in 2003 to identify the current needs of each state, determine what nuisance wildlife and damages the states encounter, and understand which mitigation methods are being used with success or failure. Four main ideas emerged from the two survey efforts; these ideas consequently steered the direction of this manual:

- Cumulatively, the states indicated a range of problems caused by numerous wildlife species relative to the operation of dams. This manual discusses 23 species with regard to their habitat, behavior, threat to dams, food habits, identifying characteristics, and management options: Muskrat, Beaver, Mountain Beaver, Groundhog, Pocket Gopher, North American Badger, Nutria, Prairie Dog, Ground Squirrel, Armadillo, Livestock (cow, sheep, horse, pig and wild pig), Crayfish, Coyote, Moles and Voles, River Otter, Gopher Tortoise, Red Fox and Gray Fox, Canada Goose, American Alligator, and Ants.
- While the states are fully aware of the potential adverse impacts wildlife activity can have on earthen dams (such as failure), private dam owners and local dam operators are often not aware of potential problems, and thus may

25: number of states that indicate animal activity has caused or contributed to unsafe dam operation or outright failure within the state.

9: number of states aware of information or guidance on the effects of animal activity on dams.

not conduct inspections with wildlife damage in mind. Local dam owners may not typically mitigate existing wildlife intrusion problems or prevent them in the future.

- States want to know how other states are successfully mitigating wildlife damages. Further, mitigation and prevention guidance should be developed and conveyed to the dam communities.

- Guidance booklets for local dam owners are needed to assist dam inspectors in identifying and mitigating animal intrusion issues.

Out of 48 states that responded to FEMA and ASDSO surveys, 25 document nuisance animals as the cause of dam failures or unsafe dam operations in their states. The U.S. Bureau of Reclamation, the National Park Service, and the U.S. Department of Agriculture document several similar cases at the federal level. State dam safety officials and federal agencies agree that animal burrows within dams can cause substantial and costly damage if left unmitigated and are consequently a major concern.

1.2 Target Audience, Purpose, and Application of This Manual

This manual provides technical guidance to dam specialists (including dam owners, operators, inspectors, state dam officials, and consulting engineers) in areas of focus identified through the two survey efforts and workshop. The purposes of this manual are to:

- Assist dam specialists in understanding the impacts wildlife can have on earthen dams.

- Provide dam specialists with basic information on habitat, range, description, and behavior of common nuisance wildlife to aid in their proper identification at the dam.

- Describe state-of-practice methods to prevent and mitigate adverse wildlife impacts on earthen dams.

- Provide state-of-practice design guidance for repair and preventive design associated with nuisance wildlife intrusion.

It is envisioned that the entire dam specialist community will use this manual to augment their routine duties in earthen dam management. This manual is presented as a process toward dam inspection and management that includes wildlife damage identification and control. This manual provides technical information and guidance on:

- How wildlife damage adversely affects the safe operation of earthen dams; specifically, hydraulic alteration, internal and external erosion, and structural integrity losses (Chapter 2.0).

- Dam inspections that incorporate a biological component to sensitize dam specialists to the aspects of their dams that attract wildlife and to understand where nuisance wildlife are likely to occur on the dam (Chapter 3.0).

- Biological data for specific nuisance wildlife to assist the dam specialist in identifying which nuisance wildlife inhabits the dam. Biological data will also assist in controlling nuisance wildlife (e.g., listed food sources can be removed to encourage the animal to leave the area) (Chapter 4.0).

- Dam design specifications and methods that can be incorporated into repair of existing dams or new dam designs to prevent wildlife intrusions (Chapter 5.0).

- Guidelines to determine when wildlife management should occur at a dam (beyond dam repair and prevention actions) and wildlife management methods that can be implemented when control of specific nuisance wildlife populations is deemed necessary. Specific methods discussed include habitat modification, use of toxicants and fumigants, trapping, and shooting (Chapter 6.0).

- The fiscal issues related to appropriate and timely wildlife management at earthen dams (Chapter 7.0).

1.3 Technical Resources Cited

The technical information provided in this manual represents the most current practices in the areas of wildlife data and management and engineering inspection and repair, as they relate to nuisance wildlife and their effects on safe dam operations. While numerous technical sources are cited throughout the document, three main sources form the backbone of this manual's technical understanding and recommendations. The first source is a manual titled *Prevention and Control of Wildlife Damage* (University of Nebraska, 1994). The data contained in the 1994 manual are considered the industry standard for pest control, and the manual is used as the handbook for those testing for licensure as pest control managers. It should be noted that the 1994 manual is under revision and a revised version will be completed February 2005. Until the release of the revised manual, the 1994 edition remains the leading guidance literature in this field and is accepted as the most current practice in nuisance wildlife management (Smith, Pers. comm., 2003; 2004). The second source is a booklet called *Prevention and Control of Animal Damage to Hydraulic Structures* (USDA, 1991). The 1991 booklet adapts some of the 1994 manual data for application to the dam environment. The last source is technical data on remedial dam repair design by Dr. B. Dan Marks, as presented in the 2001 ASDSO West Region Seminar on Plant and Animal Penetrations for Earthen Dams (ASDSO, 2001). Many other sources are also used throughout this manual to provide a cross-reference of data as well as a broad spectrum of information.

2.0 Impacts of Wildlife on Earthen Dams

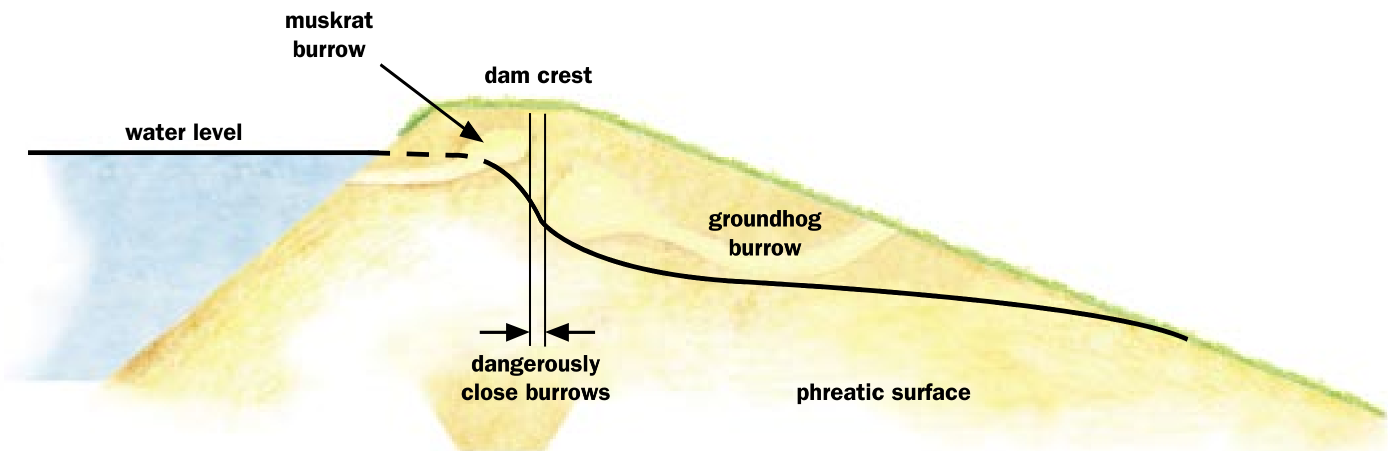


Figure 2-1. Upstream and downstream burrows can become dangerously close, causing internal erosion that may lead to dam failure.

Earthen embankment dams are used by private landowners and state and federal agencies to store farm water supplies, city water supplies, recreational waters, flood waters, and wastewater lagoons. Earthen dams rely on a thick placement of compacted soils to withstand the water pressure of the pool contained behind the embankment. Often constructed outside of developed areas, the earthen dam environment is usually near a water source and can contain a variety of vegetation; given these characteristics, earthen dam environments can be naturally conducive to use by wildlife. Wildlife inhabiting the dam can alter the dam environment through habitat establishment and use—beaver build dams, muskrat excavate dens, livestock feed on stabilizing vegetation. The natural instincts of wildlife to adapt and use their environment toward their survival can compromise the balance of engineered functions that maintain the viability of an earthen dam.

The first step in fortifying a dam against unsafe operations caused by wildlife damage is to understand what could go wrong if wildlife damage is left unchecked. While a dam owner may observe a few small burrows on the upstream and downstream slopes, it is important to understand that potential problems, like those burrows, often run deep below the surface. As such, the purpose of this Chapter is to discuss adverse engineering effects stemming from nuisance wildlife activity. Adverse effects caused by specific wildlife (as well as their identification and mitigation) are discussed in Chapters 4.0, 5.0, and 6.0.

2.1 Background

Embankment dams are vulnerable to damage from wildlife intrusions. Twenty-five states indicate that animal activity has caused or contributed to unsafe operation or outright failure of an embankment dam. Several animal species excavate burrows, tunnels, and den entrances for shelter, while other predatory animals will enlarge these structures via digging in search of prey. Similarly, herbivorous species will forage on vegetation growing on embankment dams. All of these occurrences create open areas in the embankment fill which are detrimental to the safety and performance of embankment dams. Some of these effects can be easily identified, such as surface erosion; other effects such as internal erosion may not become visible until dam safety is jeopardized.

Homogeneous and zoned embankment dams are equally susceptible to damage from animal intrusions. The ultimate consequence from the intrusions depends on the specific engineering and biological characteristics of an individual dam.

Embankment dams can be generally categorized as either homogeneous (containing one material) or zoned (containing multiple materials). Zoned embankment dams usually contain a central core designed to produce a lower phreatic surface (static water level within a dam embankment) within the downstream slope than the theoretical surface often assumed for homogeneous embankments. Due to the variability of zoned embankments, this manual discusses only homogeneous embankments.

2.2 Hydraulic Alteration

The most significant and often least obvious impact of wildlife intrusions on embankment dams is hydraulic alteration. Hydraulic alteration and its effects can manifest in different ways depending on the type and location of intrusion, including flownet distortion and physical barriers to flow.

A distorted flownet may not be a visible problem but it can have the most dramatic impact. Flownet is a term referring to the theoretical description of water flow through and under an embankment dam. The phreatic surface, equal potential lines and flow lines associated with a flownet are defined by the physical dimensions of the dam, classification of soils in the dam, and variability of the reservoir normal pool. As such, each dam has a unique flownet. The presence of animal burrows, either on the upstream or downstream slope, can distort the established phreatic surface and impact the flownet. As illustrated on Figure 2-2, upstream burrows can allow the normal pool elevation to extend into the dam embankment, forcing the phreatic surface further into the embankment. Likewise, downstream intrusions can allow the phreatic surface to day-light higher on the downstream slope. The overall effect can be a significant alteration to the phreatic surface. Dramatic changes to the phreatic surface can shorten seepage paths, increase seepage volumes, decrease the factor of safety against slope failure, and cause internal erosion of embankment materials (piping).

Of these impacts, piping is most often cited as the greatest concern among dam safety professionals because it is progressive and can rapidly lead to failure of the dam. Piping is the uncontrolled movement of soil particles caused by flowing water. As shown on Figure 2-3, piping will often start in a burrow on the downstream slope. Flowing water moves soil particles from the embankment to the burrow, leaving a void that is quickly filled with soil particles from deeper within the embankment. Because water pressure and flow generally increase further into the dam embankment, the rate of movement of soil particles will also increase. A pipe is rapidly formed extending from the downstream slope to the upstream slope. A dam breach is almost certain to develop in these instances.

External problems can also arise from wildlife activity around an embankment dam. Though hydraulic barriers can result from the activities of several species, beaver cause perhaps the largest array of adverse effects. To create deep waters in which to hide from predators, beavers compact felled tree trunks, limbs, and other materials into a mound to restrict the natural flow of a water source. As a result, the hydraulic function of the dam is altered in several ways. First, beaver mounds may block principal and emergency spillways and riser outlets, resulting in increased normal pool levels and reduced spillway discharge capacity. Second, sudden high discharges from the dam could occur if the beaver dam fails. Third, beaver dams located upstream of the embankment dam can clog water control structures as debris from the beaver dam floats downstream. Finally, erosion of the downstream toe of the dam can occur as a result of elevated tailwater caused by beaver activity.

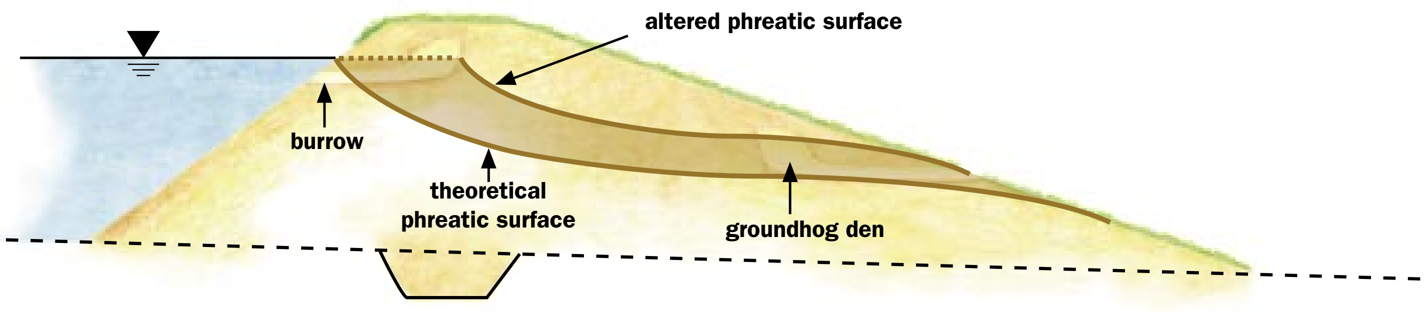


Figure 2-2. Burrows can alter dam hydraulics by shortening seepage paths.

2.3 Structural Integrity Losses

Wildlife excavate dens, burrows, and tunnels within embankment dams, causing large voids that weaken the structural integrity of the dam. Typical voids can range from the size of a bowling ball to a beach ball and much larger. Heavy rain and snow melt loosen soils surrounding a burrow, causing a localized collapse inside the burrow. In addition, a burrowing animal may encounter loose zones in the embankment (due to variability of constructed embankments) during burrow excavation, leading to a localized collapse. Animal dens also erode and collapse under the load of heavy equipment and other vehicles that use the crest of the dam as a throughway.

The collapsing soils will progressively lead to sinkholes or depressions appearing on the embankment surface. Because burrows can be under several feet of soil, the deformation or sinkhole visible at the surface could be several times the size of the original burrow. As illustrated on Figure 2-4, the collapsed soils can represent a significant portion of the dam embankment. Under the right circumstances, localized slope instability can result from a collapsed animal burrow. Depending on the location and number of collapsed burrows, dam safety or operation could be jeopardized. If portions of the crest are affected, a loss of freeboard can result, thus endangering the dam during storm events. Downstream slope failures, regardless of their extent, weaken embankment soils and reduce confinement of surrounding soils, thereby resulting in further weakening of embankment soils. Depending upon site and weather conditions, the process can progress slowly or rapidly, potentially leading to massive slope instability.

2.4 Surface Erosion

The foraging behavior of some animals on open area vegetation associated with dam embankments can reduce or eliminate vegetative cover on a dam. This increased feeding pressure on the dam's vegetative groundcover can lead to erosion paths and decreased soil retention on the dam's crest and slope. In addition, dams that are grazed by live-

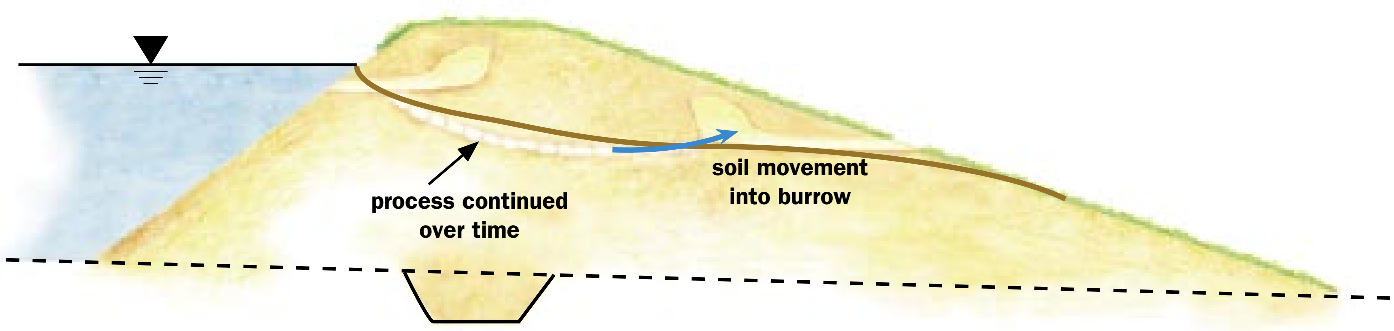


Figure 2-3. Burrows can lead to piping within an embankment.

stock often show increased rates of soil erosion because of the lack of stabilizing vegetation from grazing and trafficking, which can lead to irregular surface erosion and the formation of rills and gullies.

With continued neglect, these areas will require more than simple maintenance. In fact, given enough time, external erosion can lead to a reduction in freeboard and loss of cross section. In turn, these impacts can increase the dam's vulnerability to damage from high water during large storm events.

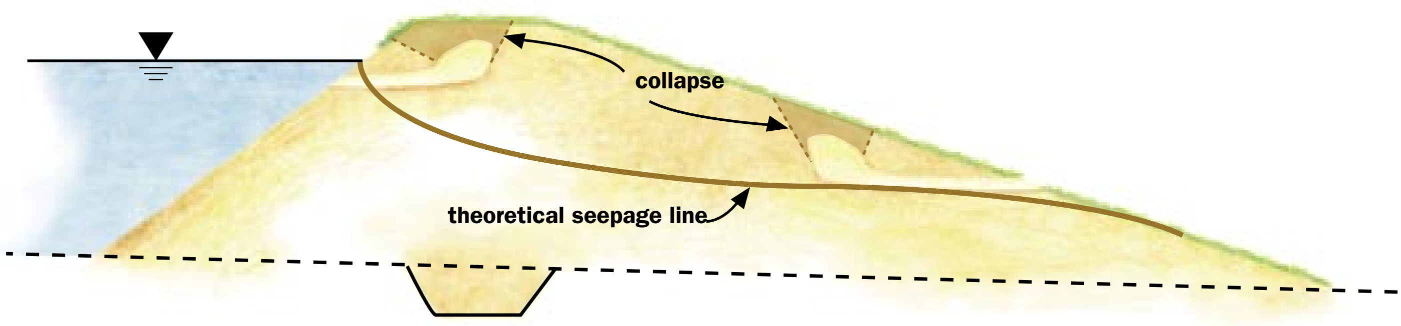
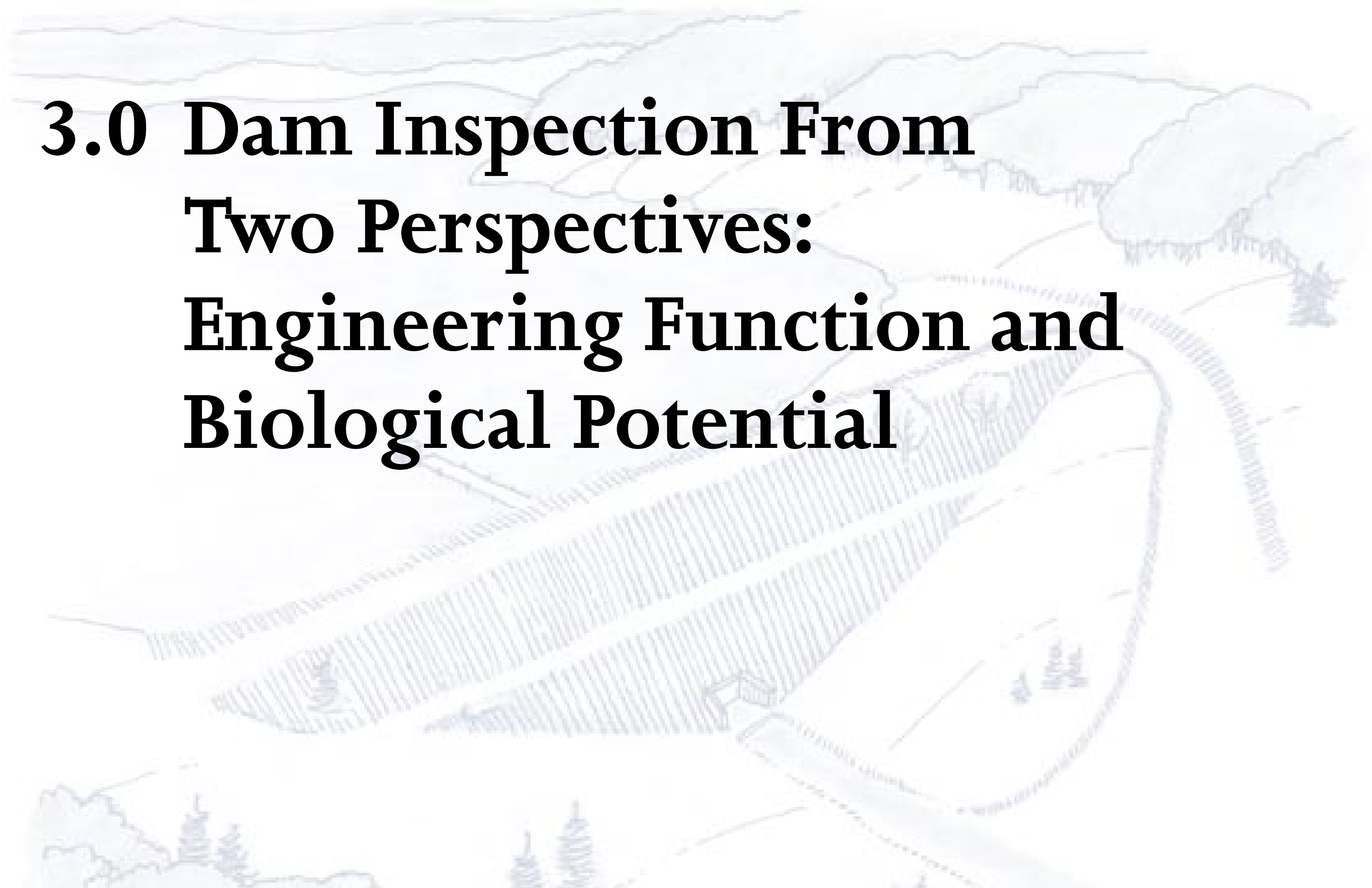


Figure 2-4. Burrows can collapse, leading to formation of sinkholes and loss of structural integrity.

3.0 Dam Inspection From Two Perspectives: Engineering Function and Biological Potential



The second step toward fortifying a dam against the effects of nuisance wildlife damage is the observation of clues left by wildlife in the dam environment. As such, regular inspection of the dam that incorporates wildlife activity recognition must be conducted by the dam owner, who is the first line of defense in protecting earthen dams. While the dam inspection is focused primarily on seepage, deformation, and structural deficiencies, the inspectors must also perceive wildlife clues left behind by dam inhabitants whose presence could cause trouble down the road. Toward this goal, this Chapter details an inspection procedure that pairs engineering inspection with key biological considerations to assist the dam specialist in viewing the dam from both perspectives (this methodology should be applied using the specific wildlife clues data presented in Chapter 4.0 of this manual).

3.1 Wildlife And The Earthen Dam

Through their natural desire to create dens, search for food, or escape predators, wildlife can cause a host of adverse impacts to an earthen dam which can lead to dam failure (refer to Chapter 2.0 of this manual for detail on the adverse impacts of wildlife activities). Though earthen dams are manmade, wildlife interacts with the earthen dam environment as if it were natural field or forest. To protect their dams, dam owners should know the biological potential of their dams—can wildlife find a suitable environment at the dam, and if so, which kind of wildlife will inhabit which locations of the dam? In answering these questions, it is helpful to know the characteristics that compose favorable habitat, and to realize that dams with diverse vegetation and site features often support a wide variety of wildlife. In assessing the dam for its biological potential, review the following relative to the dam area and surrounding areas (adapted from Benyus, 1989):

- **Vegetation Vitality:** Do the dam and adjacent areas contain dense vegetation at all levels (e.g., grass, shrub, and tree)? In general, greater variety of dense vegetation at levels ranging from groundcover to understory to canopy (regardless of vegetation type) allows for a greater variety of wildlife to inhabit the area. Small mammals, such as those discussed in this manual, prefer sites with adequate vegetation cover to hide from predators (see Chapter 5.2 for a discussion on appropriate vegetation at a dam).

- **Mini-habitats:** Do the dam and surrounding area offer vegetative diversity? Different landscapes such as prairie and forest? Sun and shade? Deep and shallow water? An environment with a mosaic landscape provides several habitat types in one area, which can support a wider variety of wildlife.

- **Transition Zones:** Is there a clear edge between one habitat type and another? At the dam environment, the dam area (a lake/pond environment) may be surrounded by a grassy field environment, a shrub edge, or a forested environment. The junction where two environments meet is called an edge, and edges are the most heavily trafficked areas in an environment (a good place to view the wildlife in and around the dam area) because they provide safe travel corridors between the two habitat types and create a more diverse habitat than either of the two habitat types.

- **Size:** Does the dam environment provide a large land area that allows wildlife to meander without having to cross roadways or come into contact with people? Most species of wildlife prefer large parcels of land that provide habitat variety without human influence.

- **Unique Characteristics:** Does the dam contain unique land features? By its very nature, the dam environment is unique because it contains a water source. Wildlife prefers a constant water source, so dams with a permanent pool will be preferable to those with a fluctuating pool, such as those used for flood control or irrigation. However, any water source will attract wildlife to some degree.

3.2 Two-Perspective Dam Inspection Methodology

The typical dam safety inspection checklist requires observation of every dam feature. The checklist is developed by an individual state's dam safety program or federal organization such as the U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, or the Federal Energy Regulatory Commission. All inspections focus on distinct physical regions, although the inspection checklists vary in length, listed inspection items, and required observations. Generally, the features are divided into clear components including:

- Upstream Slope
- Downstream Slope
- Crest
- Embankment-Abutment Contact (Groin)
- Principal Spillway
- Emergency Spillway
- Lake Drain or Outlet Works

Although inspection for animal intrusions is a facet of most if not all state inspection checklists, it is certainly not a major part of the inspection. Specific guidance on identifying animal intrusions or the typical intrusion locations of specific animals is not provided on the checklists. An inspector lacking this information may be unable to adequately inspect their dam for animal intrusions, much less adequately identify and mitigate the nuisance animal. As such, this manual presents an inspection methodology that combines engineering and biological considerations, which when viewed together, allow a dam specialist to view the dam comprehensively.

For the purposes of this manual, the dam is divided into six zones: Upstream Slope, Dam Crest, Upper Downstream Slope, Lower Downstream Slope, Downstream Toe, and Spillway, Outlets, and General Areas (Figure 3-1). The risk posed by animal intrusions is greater in some zones than in others. As such, the zones are overlapped to emphasize the critical nature of the area and to require inspection of the area twice to ensure that biological clues are sighted (ASDSO, 2001). Further discussion of the six zones relative to risk, restoration, and repair of animal intrusions is provided in Chapters 5.3 and 5.4.

When considering animal intrusions, inspection of each zone should consider not only physical evidence of an animal presence (e.g., burrow entrance), but also the habitat and biological factors that attract wildlife to the dam and sustain them once they have become established (Figure 3-2). Understanding both the engineering and biological aspects of animal intrusions into embankment dams is critical in eliminating or at least controlling the intrusions.

3.2.1 Zone 1: Upstream Slope Area

Engineering Perspective: The goal of inspecting the upstream slope of the earthen dam is to see the entire surface clearly. To ensure the inspector views the entire slope surface, the inspector must walk back and forth across the slope utilizing one of two patterns: zig-zag or parallel. In general, the zig-zag method is best for small dams and mild slopes (Figure 3-3, shown on page 17). It may prove difficult to move in a zig-zag pattern on large dams and steeper slopes, and in these cases the parallel pattern is suggested (Figure 3-4, shown on page 17).

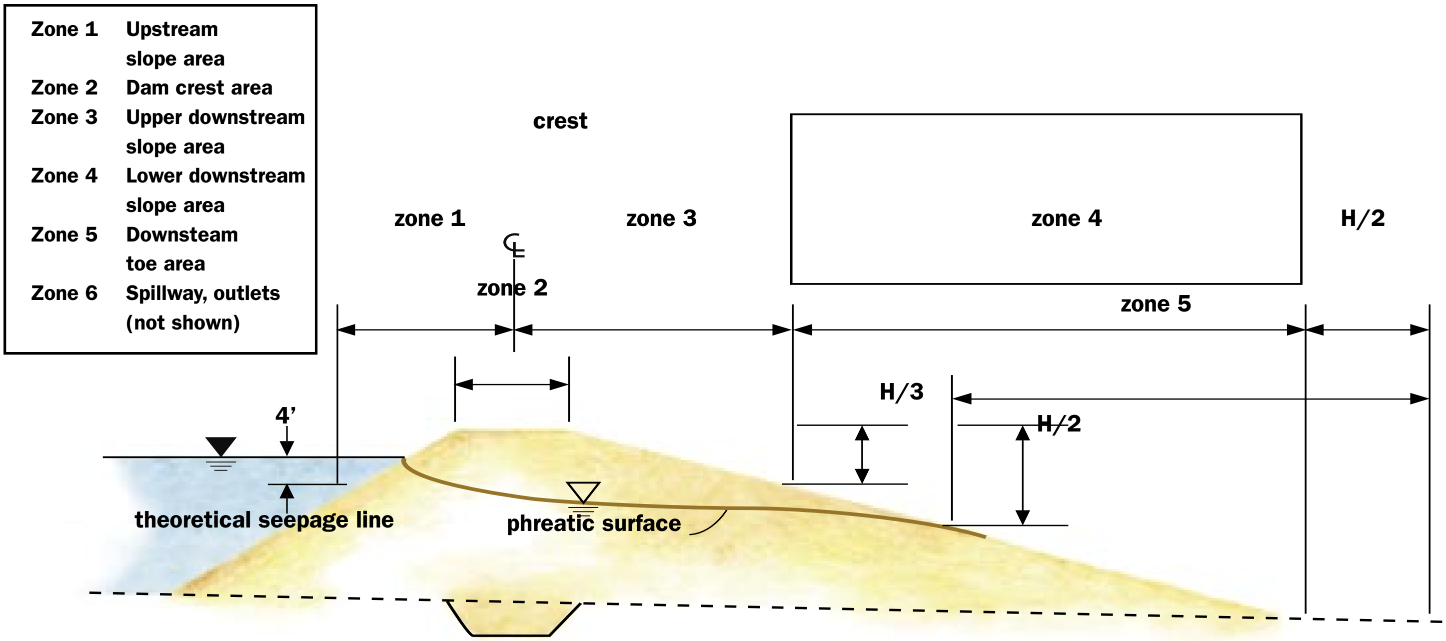


Figure 3-1. Dam Inspection Zones.

While walking the slope, the inspectors should routinely stop and view the alignment of the surface by turning their gaze a full 360 degrees. Checking the slope frequently and from many viewpoints and distances can reveal deficiencies and distortions (such as surface distortions or vegetation changes) that might otherwise go undetected. The inspectors should observe berms on the upstream slope by centering their eyes on the line being viewed and moving their body from side to side to view the line from several angles. This approach will help the inspector identify misalignments.

A typical dam safety inspection report should comment on vegetation, slope protection, erosion, instabilities, and animal burrows observed in Zone 1. When specifically considering animal burrows and other deficiencies resulting from animal activity, the inspector should look for the following: animal burrow entrances, mounds of excavated soil, debris (evidence of beaver activity), cracks, depressions, erosion, sinkholes, paths and ruts, sloughs, slides, and scarps. These conditions often indicate damaging animal activity. The inspection report should note whether the deficiencies warrant monitoring, repair, or further investigation.

Biological Perspective: This zone is primary habitat for aquatic burrowers such as muskrat and beaver, which generally burrow from 6 inches to 4 feet below the water line upward toward the crest. Nutria prefer to dig dens in the zone where land and water meet, which could be dominated by aquatic vegetation. River otters are often found living in abandoned muskrat, beaver, and nutria burrows, and can construct slides on slopes and bare areas where they repeatedly enter and exit the water. Livestock often traverse the upstream slope area—look for hoof tracks, rills, and eroded pathways. Canada geese and livestock feed on embankment slopes causing eroded areas and ruts. Crayfish and alligator may inhabit the banks and shallows of the upstream slope area. Ants may dig tunnels in the slope, loosening existing cracks. Mountain beaver or armadillo may be found along the wet edge of the pond, especially if a forest fringe or wooded area is nearby. Moles may hunt in the moist soils near the reservoir.

3.2.2 Zone 2: Dam Crest Area

Engineering Perspective: Similar to inspecting the upstream slope, the crest can be viewed using either a zig-zag or parallel pattern, with the primary goal being to view the

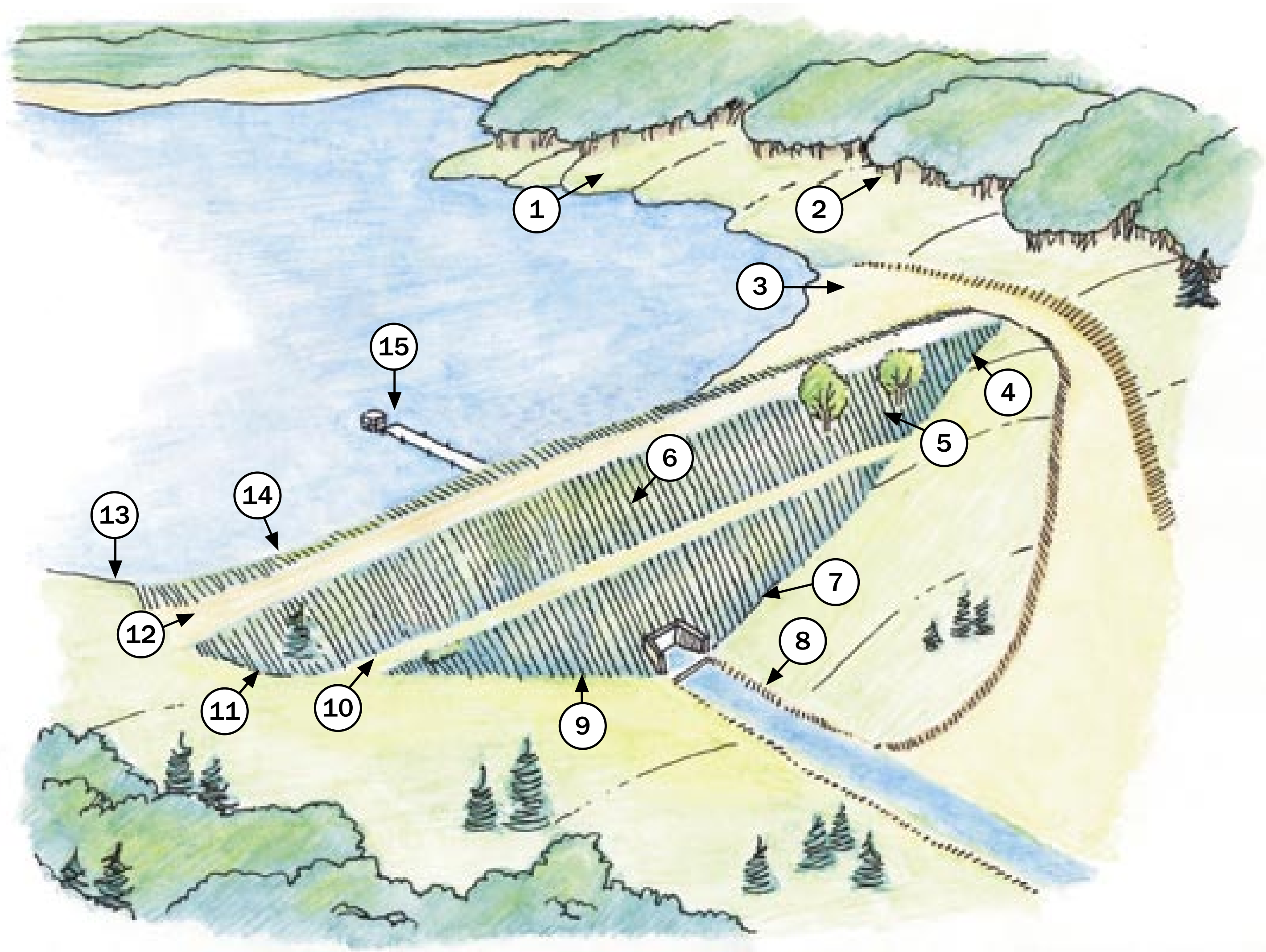


Figure 3-2. The Earthen Dam from Biological and Engineering Perspectives.

1. **Upland Areas.** Many species live in the upland areas, away from the water. Even the downstream slope, abutments, and groin areas of the dam can be considered upland in terms of habitat.
2. **Forest Fringe.** The zone between two environments (the edge) is the best place to observe those species living at and around the dam. The more habitat types at the dam, the greater number of species likely to inhabit the dam. Mountain beaver or armadillo prefer forested/wooded areas.
3. **Emergency Spillway.** Beaver often dam the spillway, causing the pond water levels to rise.
4. **Left Abutment contact.**
5. **Inappropriate Vegetation on Embankment.** Many dams contain vegetation other than mowed grass. Improper vegetation provides cover and food supply, which encourage animals to inhabit the dam.
6. **Downstream Slope.** This area is often the location where groundhogs, coyote, and fox excavate burrows. Canada geese will feed on the downstream slope, which could cause loss of protective vegetative cover and associated erosion. Species that prefer upland areas could be found in this area.
7. **Left Groin.**
8. **Discharge Conduit and Outlet Channel.** Beaver can dam the outlet structure. Aquatic species may inhabit this area depending on water flow and availability of vegetation.
9. **Toe of Embankment and right groin.**
10. **Erosion Pathways on the Embankment.** Livestock traverse the embankment creating erosion pathways.
11. **Right abutment contact.**
12. **Crest.** Livestock traverse the crest which creates ruts. The ceilings of beaver and muskrat burrows in the upstream slope are often just below the dam crest.
13. **Aquatic Fringe.** The zone where the bank meets the pond usually contains aquatic vegetation preferred by many animals such as nutria.
14. **Upstream Slope.** Beaver, muskrat, and nutria prefer the upstream slope for burrow excavation. Alligators, otters, and turtles usually live in the shallow waters near the upstream slope.
15. **Principal Spillway (with riser and trash rack).** Beavers can block principal spillways by constructing dams.

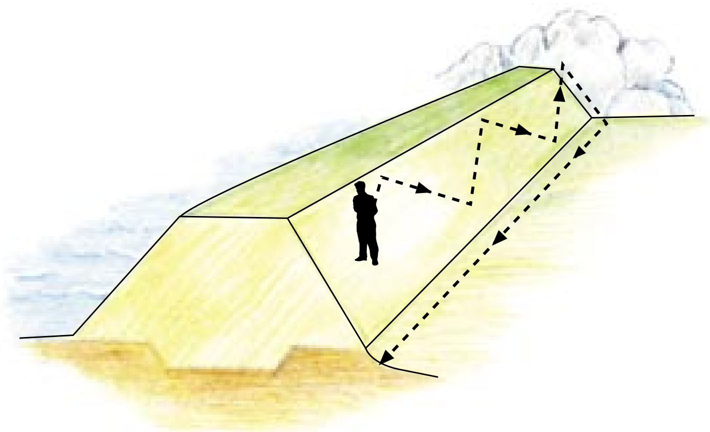


Figure 3-3. The zig-zag method of inspection is best used on small dams and mild slopes.

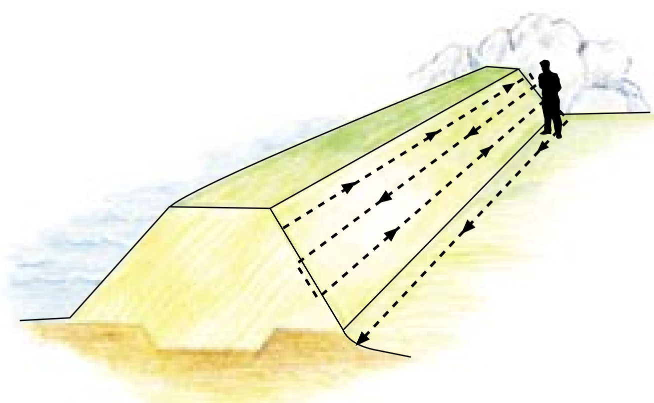


Figure 3-4. The parallel method of inspection is best used for dams with steep slopes.

entire crest from several perspectives and distances. Similar to the upstream slope inspection, the inspectors should center their eyes on the crest line, moving their body from side to side to view the line from several angles. Fixed features that can mark horizontal and vertical points along a dam can be used as reference lines; guardrails, a row of posts, or parapet walls are good reference lines (use caution when using man-made reference lines which can be moved). The reference line must be viewed from several different perspectives; first, the inspectors should sight directly on the reference line and then move their body to either side. This method will assist the inspector in detecting a change in the uniformity of the crest. Zone 2 overlaps Zone 1 on one-half of the crest width. This is intentional, and is meant to emphasize the critical nature of the area by requiring inspection of the area twice (ASDSO, 2001).

A typical dam safety inspection report should comment on width, alignment, vegetation, erosion, instabilities, and animal burrows observed in Zone 2. When specifically considering animal burrows and other deficiencies resulting from animal activity, the inspector should observe the following: animal burrow entrances, mounds of excavated soil, cracks, depressions, erosion, sinkholes, paths and ruts, sloughs, slides, and scarps. As with Zone 1, these issues can indicate animal activity. The inspection report should note whether the deficiencies warrant monitoring, repair, or further investigation.

Biological Perspective: Dens of beaver and muskrat are typically located just below the crest (look for depressions in the crest since the burrow entrance is typically underwater), and livestock often traverse the crest (look for hoof tracks, rills, gullies, and eroded pathways). Terrestrial wildlife such as groundhogs, ground squirrels, pocket gophers, foxes, coyote, and badgers may inhabit or hunt in the crest area. Moles may dig burrows in the dry, upland area of the upper upstream slope/crest that lead to their hunting grounds in the cool, moist soils near the reservoir pool. Vehicular traffic on crests may discourage wildlife establishment. Additionally, the crest is often constructed of well-compacted material, which is not attractive to most burrowing wildlife. Ants may dig tunnels in the crest, loosening existing cracks.

3.2.3 Zone 3: Upper Downstream Slope Area

Engineering Perspective: Inspecting the downstream slope is similar in method to inspecting the upstream slope. It is suggested that the downstream slope be viewed from a distance at a time of day when the angle of the sun is low so that wet areas, which will reflect sunlight, are seen more easily. Zone 2 overlaps Zone 3 on one-half of the crest in order to draw additional attention to the crest area.

A typical dam safety inspection report should comment on alignment, vegetation, erosion, instabilities, and animal burrows observed in Zone 3. When specifically considering animal burrows and other deficiencies resulting from animal activity, the inspector should observe the following: animal burrow entrances, mounds of excavated soil, cracks, depressions, erosion, sinkholes, paths and ruts, sloughs, slides, and scarps. As with the previous zones, these issues can indicate animal activity. The inspection report should note whether the deficiencies warrant monitoring, repair, or further investigation.

Biological Perspective: This zone is the most attractive for terrestrial animal activity and is preferred by groundhog, fox, and coyote for burrow and den sites. Prairie dog, pocket gopher, ground squirrel, and groundhog may inhabit the downstream slope area; if they do, predators such as badger, coyote, and foxes may choose this zone as a hunting ground. Gopher tortoises, which are strictly terrestrial, would prefer this zone as it is dry and located well-above the phreatic surface. Look for large dens, burrows, and piles of dirt outside of small burrows. Ants may dig tunnels in the slope, loosening existing cracks. Livestock and Canada geese may graze on the stabilizing vegetation. Moles may inhabit this area and dig burrows from the slope area to an adjacent outlet or spillway for the moist soils they prefer as a hunting ground. Armadillo, mountain beaver, or voles may inhabit this area if the dam is improperly vegetated with trees, shrubs, or a thick understory.

3.2.4 Zone 4: Lower Downstream Slope Area

Engineering Perspective: Inspection of this zone is similar to inspecting the upstream and upper downstream slopes, but the inspector should give greater scrutiny to the downstream slope below the pool elevation. In most embankment dams, the potential for seepage through the embankment materials day-lighting on the downstream slope increases dramatically further down the downstream slope. As shown on Figure 3-1, the theoretical phreatic surface typical for homogeneous embankment dams intersects the downstream slope. Therefore, the presence of an animal burrow in this area could shorten seepage paths, increase hydraulic gradients, and ultimately cause internal erosion of the embankment materials. A more detailed description of the potential impacts from animal intrusions is provided in Chapter 2.0.

A typical dam safety inspection report should comment on vegetation, erosion, instabilities, seepage, and animal burrows. The potential for uncontrolled seepage through animal burrows in Zone 4 is significantly greater than in the three previous zones. Therefore, seepage observations are important in Zone 4. When specifically considering animal burrows and other deficiencies resulting from animal activity, the inspector should scrutinize the following: animal burrow entrances, mounds of excavated soil, concentrated seeps, wet/spongy areas, cracks, depressions, erosion, sinkholes, paths and ruts, sloughs, slides, and scarps. As with previous zones, these issues can indicate animal activity. The inspection report should also note whether the deficiencies warrant monitoring, repair, or further investigation

Biological Perspective: This zone would also likely support terrestrial wildlife as described under Zone 3. Burrows constructed in lower Zone 4 (where it overlaps with Zone 5) will become saturated depending on depth, which is not preferred by most burrowing animals; therefore, burrows of terrestrial animals (i.e., gopher tortoise, fox, coyote, and groundhog) will occur in upper Zone 4. If a resident beaver constructs a dam that retains water, then muskrat, beaver, and otter will occupy inundated downstream slopes and outlet areas. Moles may hunt in the downstream slope if soils are moist, and the mountain beaver or armadillo may inhabit this area if the vegetation includes trees, shrubs, and a thick understory. Ants may dig tunnels in the slope, loosening existing cracks. Livestock and Canada geese may graze on stabilizing vegetation.

3.2.5 Zone 5: Downstream Toe Area

Engineering Perspective: Inspection of this zone is similar to inspecting the upstream slope and upper/lower downstream slopes, but Zone 5 is the most critical area because of the potential proximity of the phreatic surface to the downstream slope in this zone. Therefore, as in Zone 4, the presence of animal burrows in this area could shorten seepage paths, increase hydraulic gradients, and ultimately cause internal erosion of the embankment materials.

A typical dam safety inspection report should comment on vegetation, erosion, instabilities, seepage and animal burrows in Zone 5. The potential for uncontrolled seepage through animal burrows in Zone 5 is significantly greater than in Zones 1 through 3, and somewhat greater than in Zone 4. Therefore, seepage observations are critical in Zone 5. When specifically considering animal burrows and other deficiencies resulting from animal activity, the inspectors should observe the following: animal burrow entrances, mounds of excavated soil, concentrated seeps, wet/spongy areas, cracks, depressions, erosion, sinkholes, paths and ruts, sloughs, slides, and scarps. As with previous zones, these issues can indicate animal activity. The inspection report should note whether the deficiencies warrant monitoring, repair, or further investigation.

Biological Perspective: Burrows constructed in Zone 5 will become saturated depending on depth, which is not preferred by burrowing terrestrial animals (i.e., armadillo, mountain beaver, vole, mole, gopher tortoise, fox, coyote, and groundhog). If a resident beaver builds a dam that retains water, then muskrat, beaver, nutria, and otter will occupy inundated downstream slopes and outlet areas, if appropriate vegetation has become established. Ants may dig tunnels in the slope, loosening existing cracks. Livestock and Canada geese may graze on stabilizing vegetation.

3.2.6 Zone 6: Spillway, Outlets, and General Areas

Engineering Perspective: The best approach to inspecting spillways and outlets is to view all surface and internal areas by walking closely along or within the structure, observing confined space entry requirements. The inspector should enter the conduit and view the internal structure using a flashlight, providing the conduit is of the appropriate size and in safe repair. The inspector should use binoculars or a camera/video camera with the appropriate lens to document the conduit condition if the conduit is not accessible (e.g., located in the water separated from the shoreline or embankment). Underwater features can be viewed via use of boats or underwater divers. Shorelines and upstream areas should be inspected by walking or using vehicles to traverse the inspection areas. Other appurtenant works should be inspected up-close.

Biological Perspective: Beaver will construct dams at the spillway locations to capture and reroute water flow. Look for gnaw marks in a circular pattern on tree trunks, beaver dams, and otters playing in the beaver dam waters. Aquatic animals such as muskrat and nutria may be found at these locations if the beaver dam retains water, and if sufficient aquatic vegetation has become established. Armadillo or mountain beaver may inhabit the area if a forest fringe or wooded area is adjacent to the water source.

4.0 Overview and Identification of Nuisance Wildlife

The FEMA/ASDSO workshop and 2003 dam safety specialist surveys indicate that several species damage earthen dams across the nation. This Chapter discusses 23 animals identified by the states as presenting the greatest threats to safe dam operations. Tracks, photographs, and range maps are provided for each animal, as well as a description of the specific threats each animal poses to the earthen dam environment, its preferred habitat, food habits, behavior, and field-identifying tips specific to each animal. It should be noted that some information is difficult to present depending on the animal (e.g., crayfish tracks) and in these cases, such information is omitted.

In a general sense, it is envisioned that a dam specialist will use this information to gain a better understanding of the wildlife that inhabits a dam. To a greater degree, it is hoped that this information will go hand in hand with overall dam management to assist a dam specialist in knowing where to look for wildlife damage (e.g., burrow sites), indicate which animals caused the damage via specific descriptors, and lead the dam specialist toward appropriate damage repair, prevention, and wildlife management (see Chapters 5.0 and 6.0 for dam repair, damage prevention, and wildlife management methods).

4.1 The Importance of Accurate Wildlife Identification

During the regular dam inspection detailed in Chapter 3.0 of this manual, the dam specialist will have viewed the dam from both engineering and biological perspectives. In doing so, the specialist may have identified burrows just below the water-line, observed floating rafts of vegetation on the water, trails from the water to the bank, and noted an abundance of aquatic vegetation along the shoreline. Application of the information in this chapter will assist the dam specialist in putting the above clues together to determine which animal is damaging the embankment.

Given the dynamic nature of wildlife and its desire to avoid human interaction, a dam owner will seldom witness wildlife causing damage to dams. However, proper identification of nuisance wildlife is critical so that dam repair and wildlife management methods can be appropriately and lawfully applied to mitigate specific species and their impacts to the earthen dam.

A dam environment that has high biological potential (refer to Chapter 3.1 for discussion of biological potential) will most likely support several nuisance species; however, not all species living at the dam are necessarily in need of management. To apply mitigation that blankets all animals seen at the dam may be a waste of time and money, not to mention unnecessarily damaging to the environment. For this reason it is important to carefully evaluate the biological evidence at the dam to accurately identify the species responsible for the damage. For example, beaver and otters often live in the same environment, and otters often opt to use beaver dens instead of creating their own. In this case, the otter may be seen living in the den, but the beaver is the species actually responsible for the burrowing activity. Therefore, mitigation should be geared toward the beaver, and not necessarily the otter, which will live in hollow logs and rock crevices just as comfortably. On the other hand, several species may be responsible for compromising activities at the dam, and dam repair, prevention action, and wildlife mitigation will need to be geared toward several species. In essence, application of the information provided in this Chapter will assist in accurate identification of the problematic species, which will help the dam specialist appropriately manage the dam without spending unnecessary energy or funds.

Misidentification of a wildlife species may result in inadequate mitigation, which could allow damage to continue, perhaps leading to dam failure. As wildlife identification can be difficult, a dam owner may benefit from using a wildlife specialist or professional trapper to positively identify the species so that proper wildlife mitigation can be developed. Appendix A contains state wildlife contacts, and state trapper information can be obtained at www.nationaltrappers.com.

4.2 Identifying Nuisance Wildlife

4.2.1 Muskrat Overview

Muskrat(Ondatra zibethicus) are semi-aquatic rodents with brownish-black fur and with a body 10-14 inches long and a tail 8-11 inches long. Muskrats have large, partially-webbed hind feet and a vertically flattened tail, which they use to propel themselves through water.

Threat to Dams: Muskrats dig fairly large burrows that can lead to internal erosion and structural integrity losses in the earthen dam. Muskrats will continue to dig upward into the embankment as the phreatic surface rises; internal burrows can become extensive.

Habitat and Home (Figure 4-1): Muskrat inhabit freshwater and saltwater marshes, lakes, ponds, rivers, and other watercourses, where water is calm or very slowly moving. Muskrats prefer water courses that are about 3-4 feet deep that don't freeze completely in the winter and contain abundant cattails or aquatic vegetation. Muskrats typically burrow

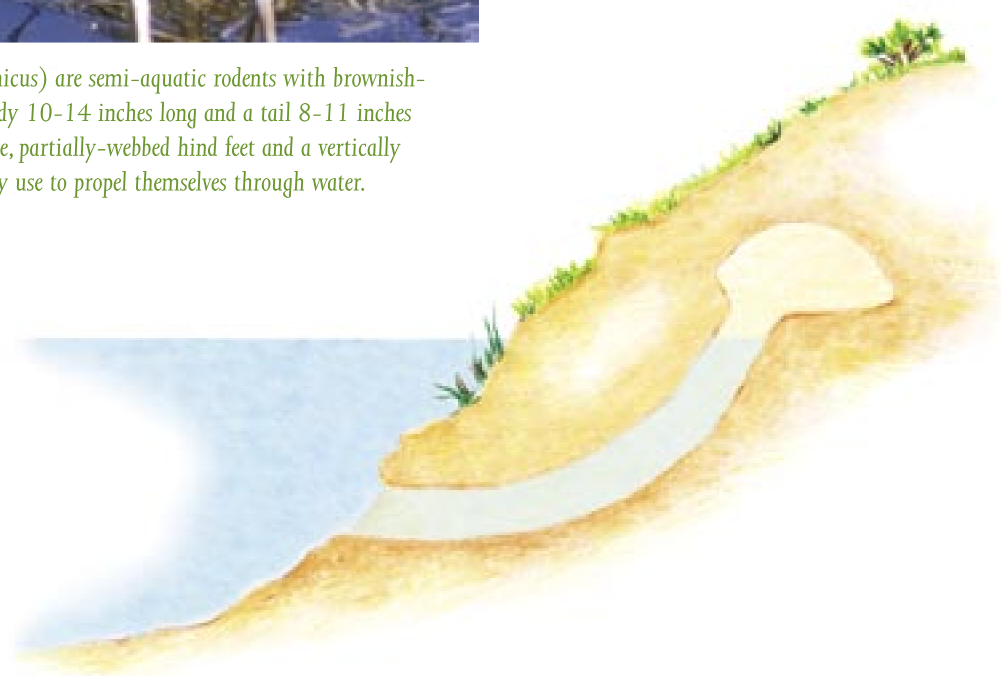
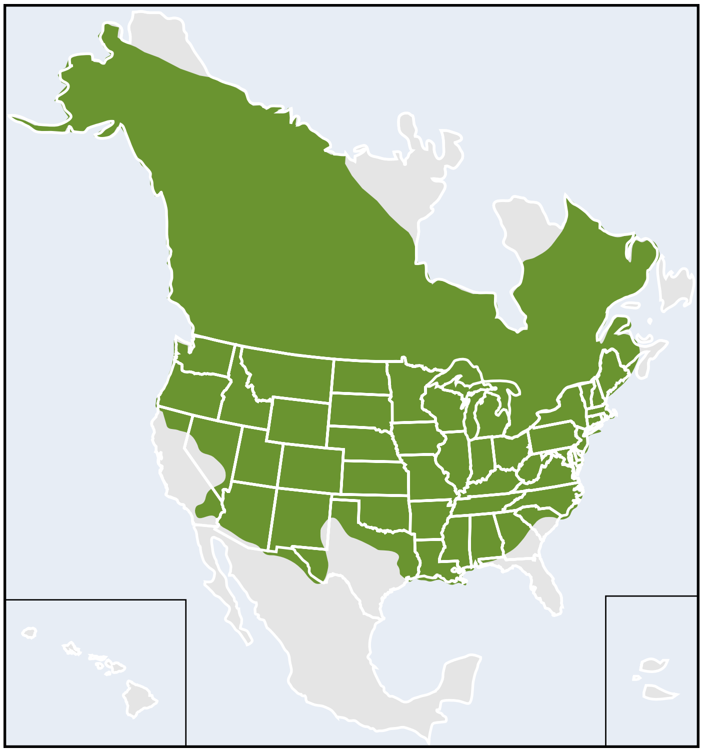
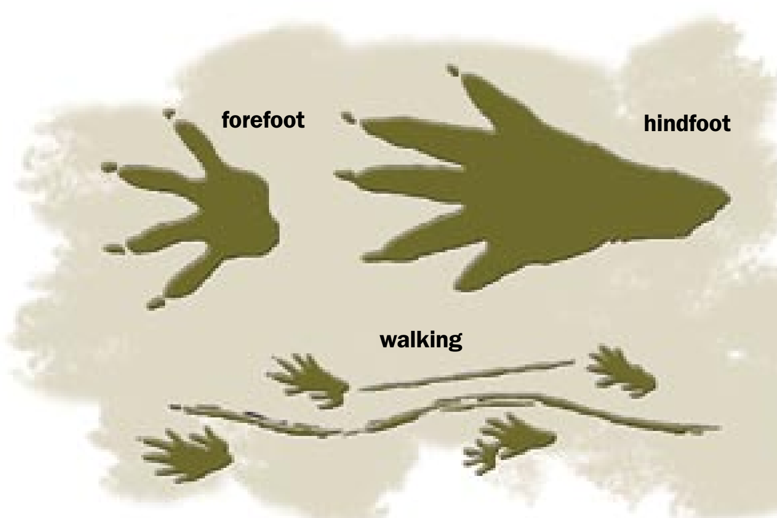


Figure 4-1. Muskrat dig dens in the upstream slope, with the entrance tunnel beginning about 6-18 inches below the water line.



Range of the muskrat in North America.



In very clear tracks, a small fifth toe can be seen on the outside of the front foot pad. All toes, except the nubbin, will show claw prints. The muskrat's vertically flattened, bare tail will create a drag mark in the center of the prints.

into a dam's upstream face. Their burrows begin from 6 to 18 inches below the water surface, and breather holes and escape holes can be observed above the water line. If the water level rises, the muskrat will excavate a dry chamber by digging higher into the embankment at an upward slant. Muskrats also build conical houses out of marsh vegetation, but usually excavate and use burrows when inhabiting earthen dams and other hydraulic structures (USDA, 1991). Detection of muskrat can be difficult if slopes of the dam are improperly vegetated, as their burrows may be covered over (see Chapter 5.2 for a discussion on improper vegetation at an earthen dam).

Muskrats are considered a significant dam safety issue in 71% of the surveyed states.

Food Habits: Muskrats are primarily herbivores and prefer to feed on cattails, grasses, smartweed, duck potato, water lily, sedges, and other aquatic plants. When vegetation is scarce, muskrat will feed on bivalves, crustaceans, insects, and sometimes fish (University of Nebraska, 1994).

Behavior: Muskrats can often be seen swimming at any hour of the day however they are most active at twilight. Muskrats often construct roofs over floating rafts of vegetation so that they have a covered place to eat. These huts can be found floating on the water and are especially important to the muskrat in winter when cooler weather can chill the animal's naked tail and feet (USDA, 1991; Benyus, 1989).

Field Tip: Listen for a loud splash when nearing the water. Muskrats plop into the water when approached to alert other muskrat of human activity. Muskrats sometimes hold their tails out of the water as they swim (Benyus, 1989).

4.2.2 Beaver Overview

The Beaver (Castor canadensis) is the largest rodent in North America weighing 45-60 pounds, with a body measuring 25-30 inches and a tail measuring 9-10 inches. Beavers are typically aquatic mammals, with webbed feet that are adapted for swimming and a flattened tail. Beavers vary in color but the most common body fur is reddish-brown and the belly fur is usually gray (USDA, 1991).

Threat to Dams: Beaver can cause extensive damage to earthen dams by excavating bank burrows, which can cause internal erosion or structural integrity losses. Beaver dams constructed across spillways can cause adverse hydraulic effects and result in flooding or failure of the spillway or the earthen dam itself. Beavers often clog the intake and outlet structures with their cuttings.

Habitat and Home: (Figures 4-2, 4-3, 4-3A and 4-4): Beaver can be found throughout the continental United States wherever there is a year-round source of water. However, beaver will avoid an aquatic site that does not contain preferred foods or have adequate sites for lodges, dens, or dams (University of Nebraska, 1994). Beaver lodges are easy to identify; they are dome-shaped, built of limbs and

Beavers are considered a significant dam safety issue in 67% of the surveyed states.

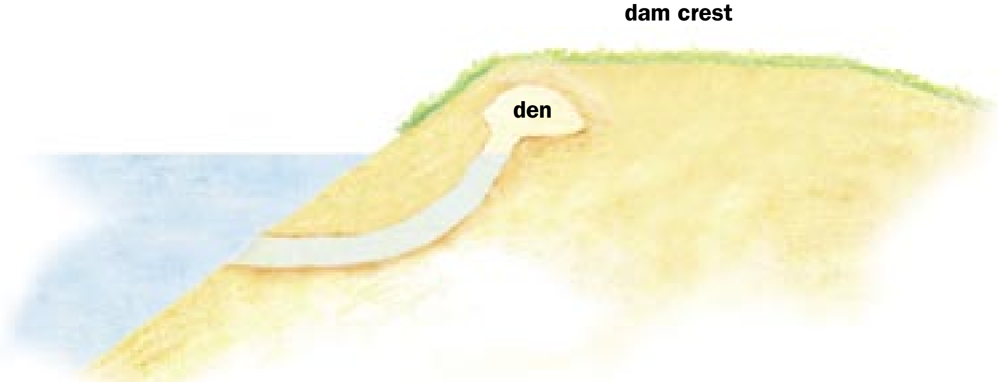
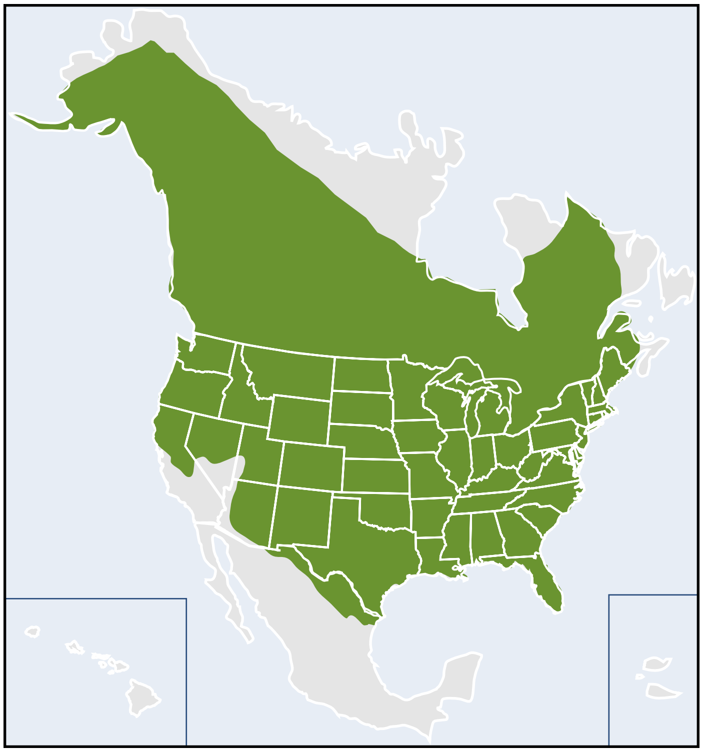


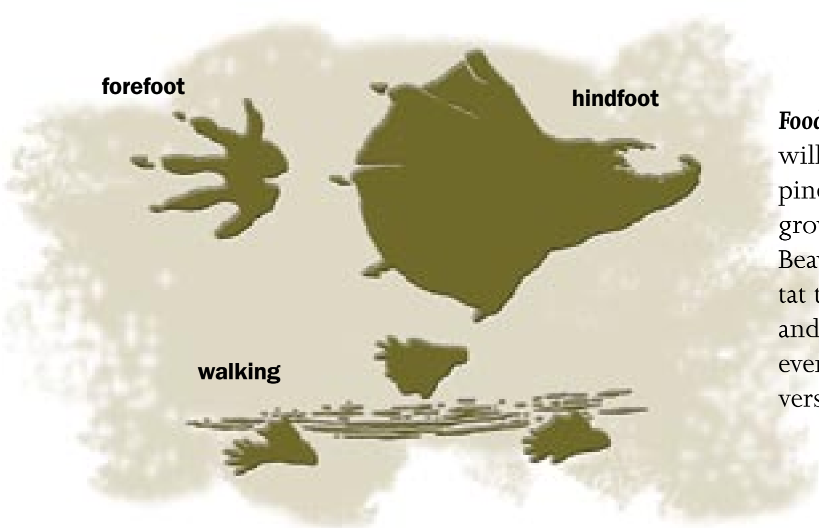
Figure 4-2. The ceiling of a beaver den is often just below the crest of the dam.

logs, may reach 5-6 feet above the water line, and be 12-14 feet wide (Benyus, 1989). Beavers have also been known to create tunnels and dens. Beaver tunnel entrances have been observed 1-4 feet below the water level. Beavers burrow into the dam from below the water line upwards toward the crest, where the beaver will excavate their den. The entrance to the lodge or bank den is typically under water, with the interior den being several inches above the water surface. All lodges and bank dens have at least two entrances, and perhaps four or more (University of Nebraska, 1994).



Range of the beaver in the North America.

Beaver dens are often excavated just below the dam crest within the dam. A den roof collapse at this location can create voids in the crest and upstream slope.



Beaver tracks are not a reliable way to identify their presence due to their walking pattern. The beaver's hind foot is placed on top of the front foot's track and the wide tail, which drags along the ground, smears both to a point where identification becomes nearly impossible.

Food Habits: Beaver prefer to eat tree species such as aspen, willow, poplar, cottonwood, sweetgum, blackgum, and pine, although beaver will also eat most woody plants that grow near water, as well as herbaceous and aquatic plants. Beavers will travel 100 yards or more from their water habitat to cut down crops or trees growing in adjacent habitats and drag them back to their pond home. Beaver use whatever vegetation they don't eat for dam construction (University of Nebraska, 1994).

Figures 4-3 and 4-3A. Beaver dams can block emergency spillways causing water levels behind the dam to rise.

Figure 4-4. A lodge can reach 5-6 feet above the waterline.

The ranges for beaver, nutria and muskrat overlap, and their damages can appear similar. Careful examination of the damage, burrows, and proper use of the field tips listed in this manual will assist in accurate species identification and management.

Behavior: Beavers construct dams to create a depth of water suitable for them to hide from predators as they travel to their shore feeding grounds. Beaver use a variety of materials to construct these dams—the use of wood, fiber, metal, wire, and rocks is not uncommon. Beavers leave their lodge at dusk and spend most of the night working (removing shoreline trees, constructing dams, gathering food). However, in the fall season it is not uncommon to see a beaver working in the daytime as they gather food for the winter (Benyus, 1989).

Field Tip: Perhaps the best indication of beaver is their dams. Dams are typically a few feet long, but can be up to several hundreds of feet long. A second indication is the presence of canals, which beaver build in the water to help them transport the trees they fell to construct the dams. Gnaw marks in a circular pattern on tree trunks are also good indicators of beaver, and trees cut by beavers show a distinctive tapered cone at the end of the trunk. An audible sign of beaver is the loud slap of their horizontally flattened tail on the surface of the water to alert other beaver to the presence of predators (Benyus, 1989).

4.2.3 Mountain Beaver Overview

Mountain Beaver (*Aplondontia rufa*) is typically found in Washington, Oregon, and portions of California. Mountain beaver neither prefer mountainous habitat nor are true beavers. These rodents have short, heavy bodies and are dark brown above and lighter brown below; they resemble a tailless muskrat. Mountain beavers have long, strong claws, which they use to create burrows up to 19 inches in diameter in wet soil near dense water-side vegetation.

Threat to Dams: Mountain beavers divert waterflow by blocking water with vegetation. The shallow location of the extensive burrows will often cause the ground to cave in. The mountain beaver's activities could result in hydraulic alteration and structural losses.

Habitat and Home: Mountain beavers prefer habitats in forested areas where the canopy is open enough to allow dense understory vegetation. If a dam is covered with trees and thick understory, then a mountain beaver will likely find a comfortable habitat. Within this area, mountain beaver prefer moist gullies, and vegetated hillsides or flat areas that are not prone to flooding. Habitats dominated by red alder, salmonberry, huckleberry, and bracken and sword ferns are preferred by the mountain beaver. Mountain beavers dig extensive burrows that can cover a quarter-acre, are usually located near vegetative cover, and are generally 1-6 feet deep with 10-30 open entrances. The burrows contain deep (1-9 feet) nesting and food chambers usually located about 3 feet below ground surface; the chambers can be large, usually measuring 2 feet in height and 2 feet in diameter. Mountain beavers do not like their burrows to be wet and will leave a burrow once it is flooded (University of Nebraska, 1994) (Figure 4-5).

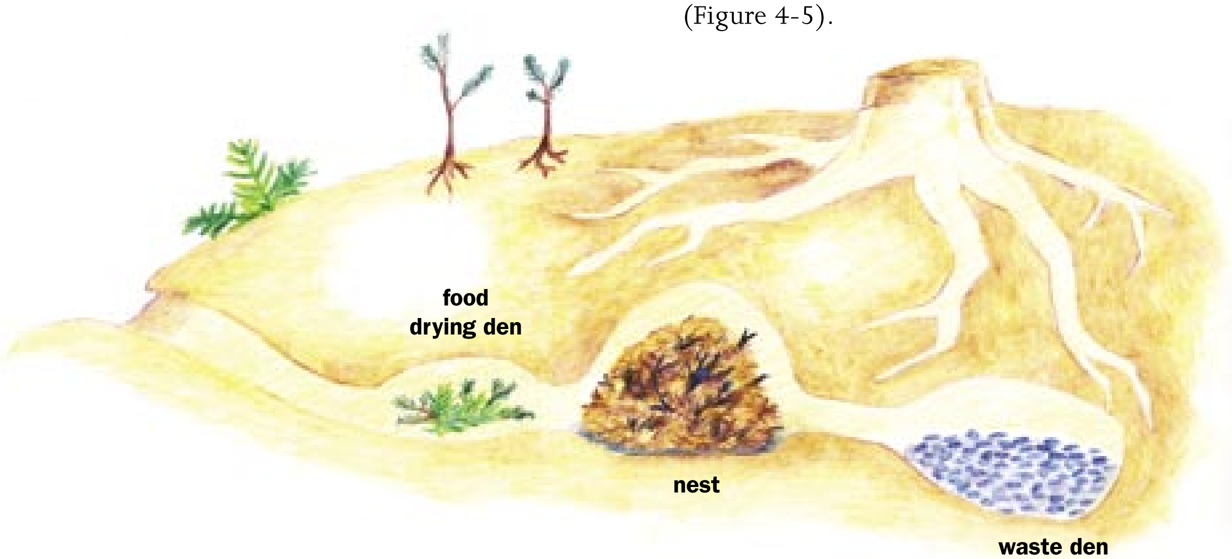
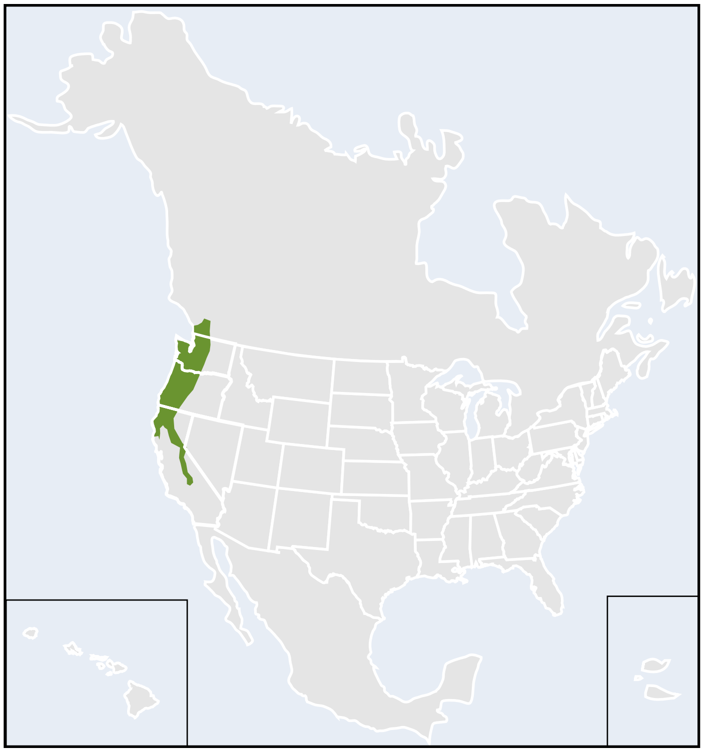
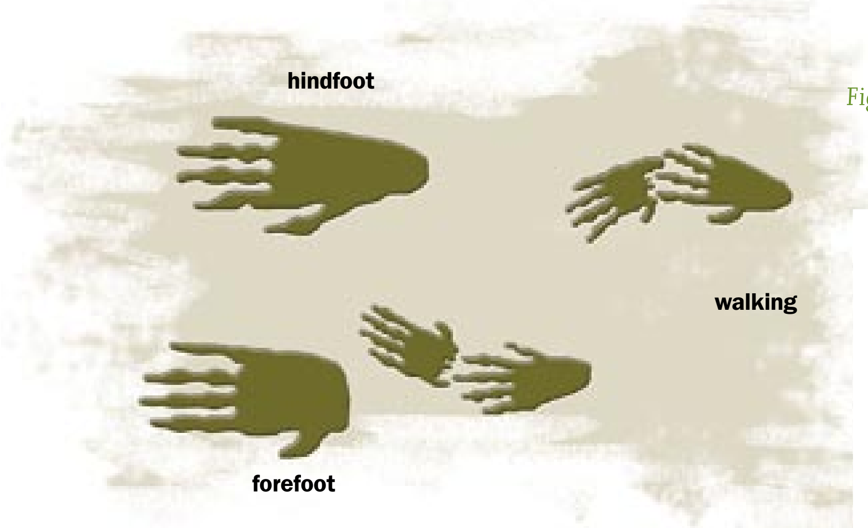


Figure 4-5. The mountain beaver only leaves its den to forage or create new dens.

Food Habits: Mountain beavers are herbivores and eat any type of succulent vegetation, with sword fern and bracken fern being favorites (University of Nebraska, 1994). Mountain beavers will also girdle the base of trees and feed on small stems (Figure 4-6). Plants that are gathered by the mountain beaver are often dried near the burrow and are probably used for storage or nesting material. Mountain beavers dry their food by stacking vegetation on a nearby log or rock, which is termed "haystacking" (Figure 4-7). Mountain beaver usually feed on plants located within 50 feet of their burrows (University of Nebraska, 1994).



Range of the mountain beaver in North America.



The identifying characteristic of a mountain beaver track is a front foot print that has a square heel and a hind print that displays a tapered heel.

Figure 4-6. Mountain beavers girdle trees and feed on small stems.

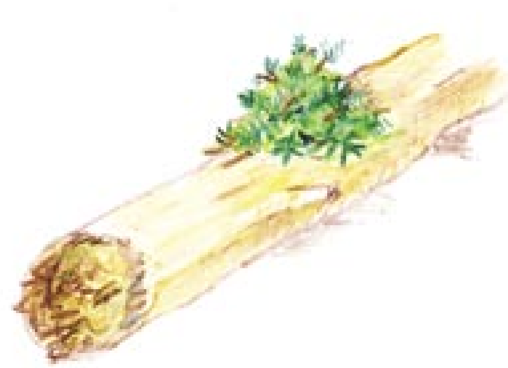


Figure 4-7. Mountain beavers dry their vegetation on logs, known as "haystacking," before moving it into their burrows. Haystacks can be up to 2 feet high.

Figure 4-8. Ferns and Douglas fir branches placed in a burrow is a reliable field sign of mountain beaver.

Behavior: Mountain beavers are nocturnal animals. They are superb diggers and spend much of the night digging and maintaining their labyrinth of burrows. Mountain beavers often stack cut vegetation in a burrow entrance, presumably to lower the vegetation's moisture content before storing it in the burrow (University of Nebraska, 1994).

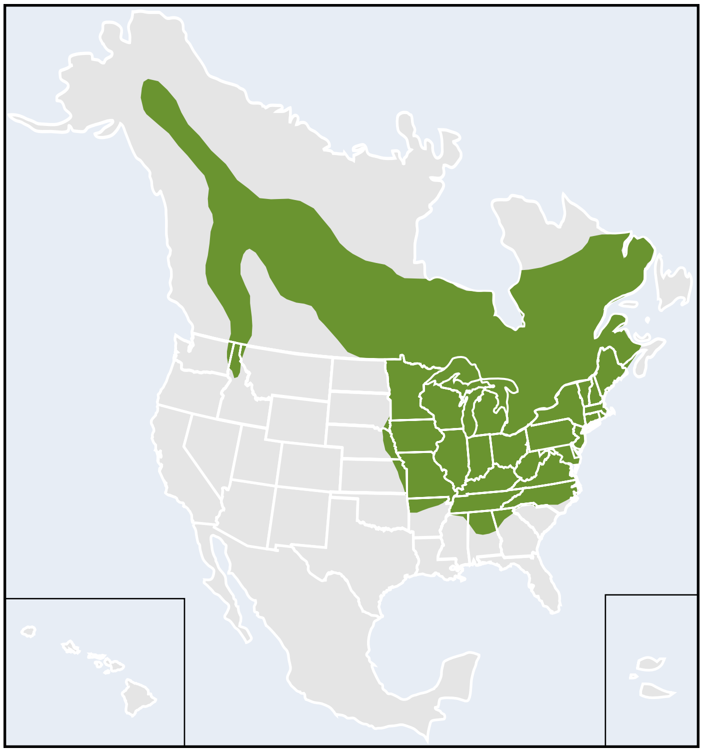
Field Tip: Stem and branch cutting within the vicinity of the dam may be a positive sign of mountain beavers. Signs of mountain beaver include freshly dug soil and chewed vegetation in proximity to a 6 to 8-inch diameter hole. Look for haystacks near the burrow entrance and vegetation piled in the burrow entrance (Figure 4-8).

4.2.4 Groundhog Overview

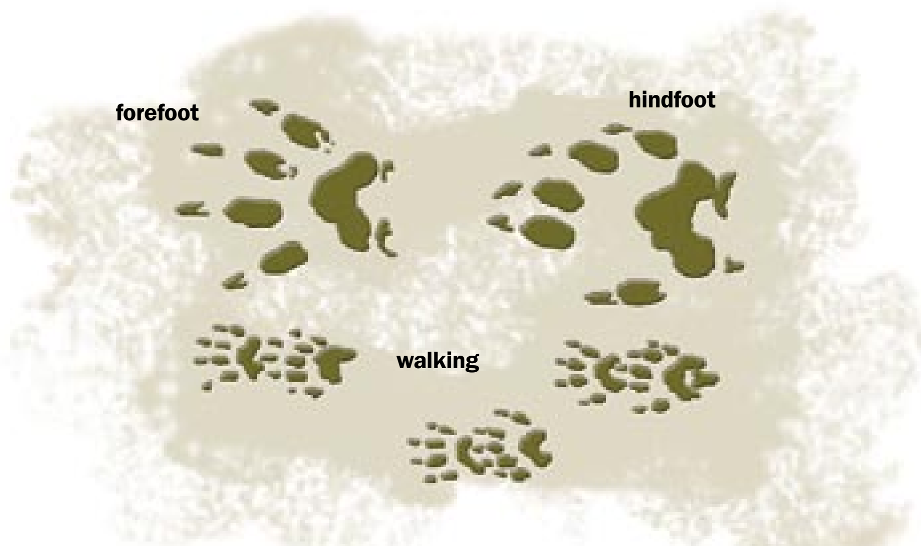
Groundhog (Marmota monax) (also known as Woodchuck or Rockchuck) are large burrowing rodents that weigh an average of 5 to 10 pounds and have an average body length of 16-20 inches. Groundhogs are usually grizzled brownish gray, although white and black individuals may occasionally be found. The groundhog's forefeet have long, curved claws that are well adapted to digging burrows (University of Nebraska, 1994).

Threat to Dams: Groundhog burrows in earthen dams can weaken the embankment and act as a pathway for seepage.

Habitat and Home: The groundhog generally prefers open farmland and woody or brushy areas adjacent to open land. Groundhog burrows are usually located in fields or near grassy pastures or meadows, along fence rows, stone walls, roadsides, and near building foundations or the bases of trees (University of Nebraska, 1994) (Figure 4-9, shown on page 31). Groundhogs will burrow into earthen dams, generally on the downstream side of the dam, as this environment can be similar to their preferred habitat (Michigan State University Extension, 1998). Their burrows can be distinguished by the large mound of excavated earth deposited by the main entrance. Two or more entrances generally exist for each burrow system. Burrows are often well-hidden and may be difficult to locate.



Range of the groundhog in the North America.



It may be difficult to tell the front and back tracks apart because when a groundhog walks, it puts its hind foot in the track of its front foot.

Food Habits: Groundhogs are strict herbivores. They feed on a variety of vegetables, grasses, and legumes, including beans, peas, carrot tops, alfalfa, and clover. Groundhogs prefer to feed in the early morning and evening hours (University of Nebraska, 1994).

Behavior: Groundhogs are usually only active during the day. During warm periods, they can often be found basking in the sun near their burrows. Groundhogs are one of the few mammals that enter a true hibernation period. Hibernation generally occurs from late October or early November to late February or March, although the exact timing depends on the latitude (University of Nebraska, 1994). New burrow construction occurs in late summer (USFS, 1994).

Field Tip: When approached or startled, a groundhog will often emit a shrill whistle followed by a low, rapid warble (University of Nebraska, 1994). An indicative sign of a groundhog burrow is the spring cleaning performed by the groundhog, which results in a mound of fresh dirt outside the burrow entrance. Adjacent trees may be girdled or clawed (Indiana Department of Natural Resources, 2003). Look for burrow construction in the late summer months.

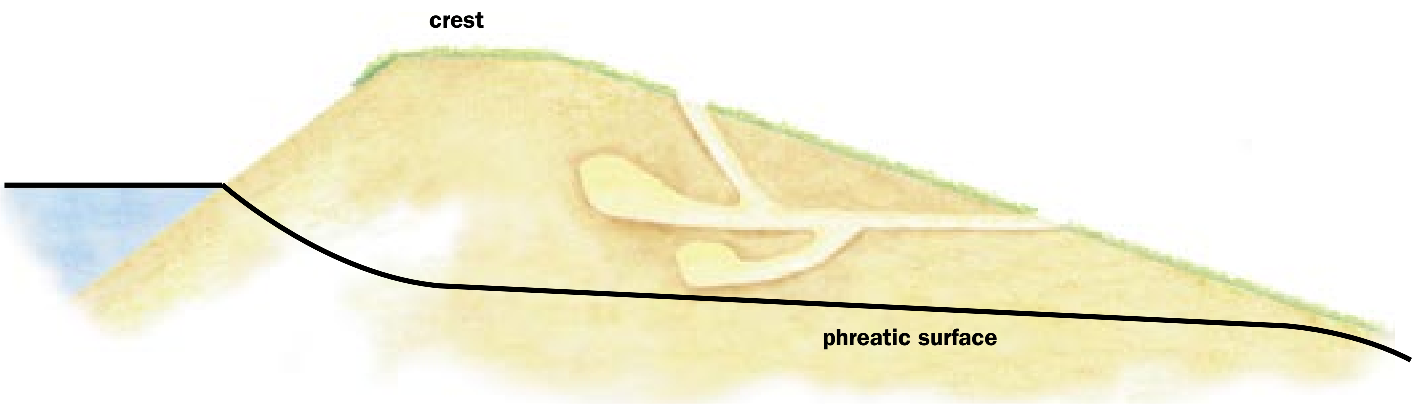


Figure 4-9. Groundhog burrows are extensive and irregular in pattern.

4.2.5 Pocket Gopher Overview

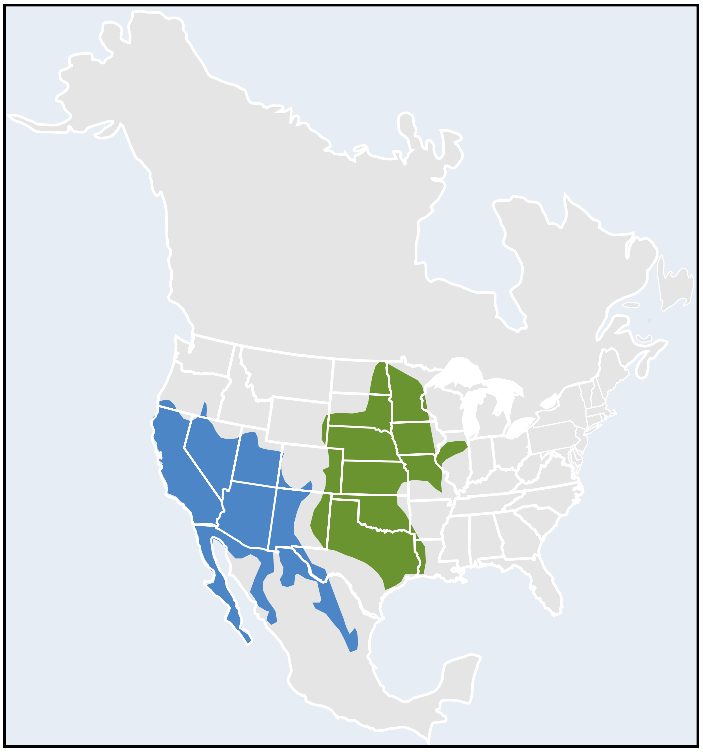
Pocket Gopher (Geomys spp., Thomomys spp., and Pappogeomys castanops) are medium-sized burrowing rodents that weigh an average of 3 to 20 ounces and have an average body length of 5 to 14 inches. Their fine fur is highly variable in color, ranging from nearly black to pale brown to almost white. Pocket gophers have fur-lined pouches outside of the mouth that are used for carrying food. They have yellowish-colored incisor teeth that are always exposed, even when the mouth is closed.

Pocket gophers are considered a significant dam safety issue in 23% of the surveyed states.

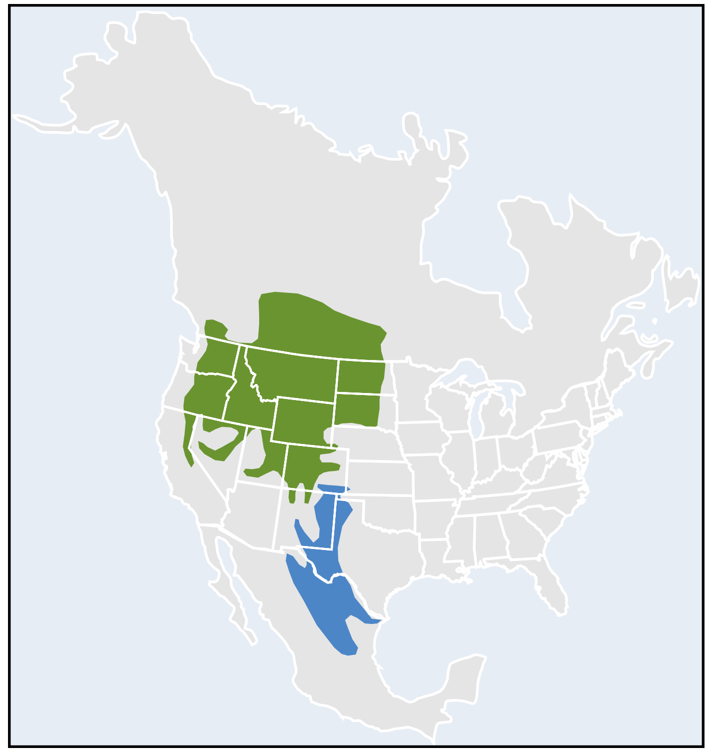
Threat to Dams: Pocket gophers are generally only a threat to small earthen dams. They dig burrows that can lead to internal erosion and structural integrity losses in the dam. The presence of pocket gophers also increases the likelihood of badger activity. Badgers are one of the primary predators of pocket gophers. Badgers will attempt to dig gophers out of their burrows, which can be very destructive to earthen dams (See Chapter 4.2.6 for a discussion on badgers). Pocket gophers can also damage underground utilities, such as irrigation pipes or electric cables (USDA, 1991).

Habitat and Home: There are 10 species of pocket gopher with substantial populations in the United States, but only one species is typically found in an area (USFS, 1994). They can occupy a wide range of habitats, from low coastal areas

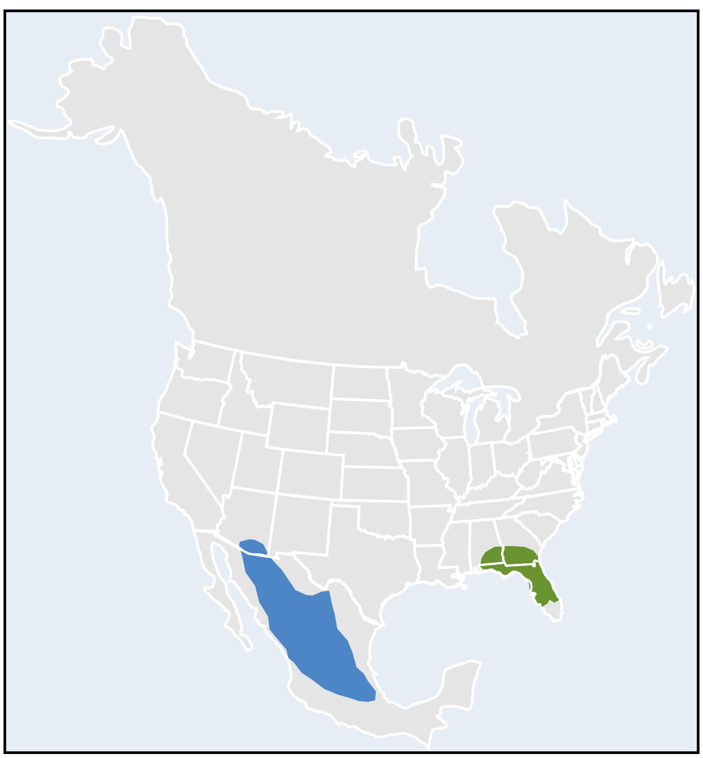
Range of the pocket gopher in North America.



Plains (Geomys bursarius), and Botta (Thomomys botta) Pocket Gophers



Northern (Thomomys talpoides), and Yellow-Faced (Pappogeomys castanops) Pocket Gophers

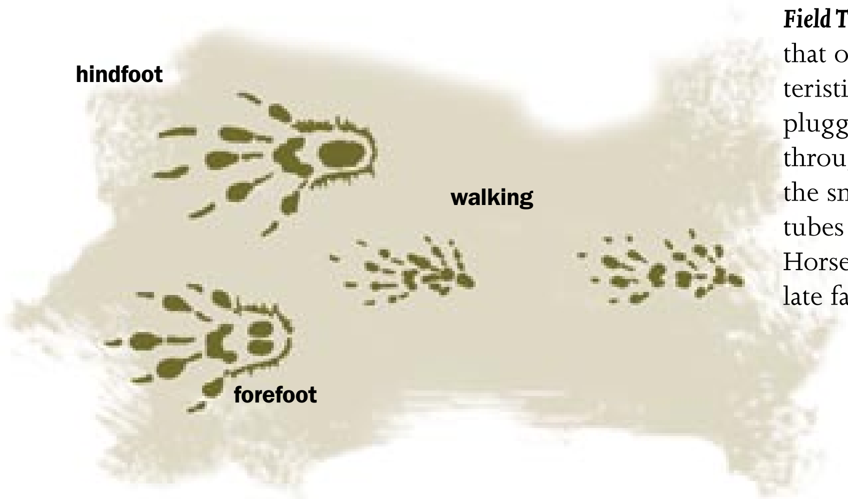


Southeastern (Geomys pinetis), and Southern (Thomomys umbrinus) Pocket Gophers

to mountains (USDA, 1991). Horseshoe-, fan- or kidney-shaped mounds of soil are characteristic evidence of pocket gopher burrows. Their burrows are nearly always kept closed with an earthen plug (University of Nebraska, 1994) (Figure 4-10).

Food Habits: Pocket gophers are strict herbivores, eating all types of forbs, grasses, shrubs, and trees. Roots are the major food source, although during the growing season, pocket gophers will also eat the above-ground portions of plants (University of Nebraska, 1994).

Behavior: Pocket gophers are solitary animals that spend much of their time underground. There is typically only one gopher per burrow, except during breeding season (USDA, 1991).



Pocket gopher tracks will show five toes on the hindfoot and four toes on the slightly smaller forefoot. Claw marks are usually well-defined.

Field Tip: Pocket gopher activity can be distinguished from that of other burrowing animals by their burrow characteristics, particularly the fan-shaped mounds of soil and plugged burrow entrances. Pocket gophers will tunnel through the snow, pushing soil from below ground into the snow tunnels. When the snow melts, the soil "casts" or tubes can be found on the ground surface (USFS, 1994). Horseshoe-shaped mounds of soil are created in summer or late fall.

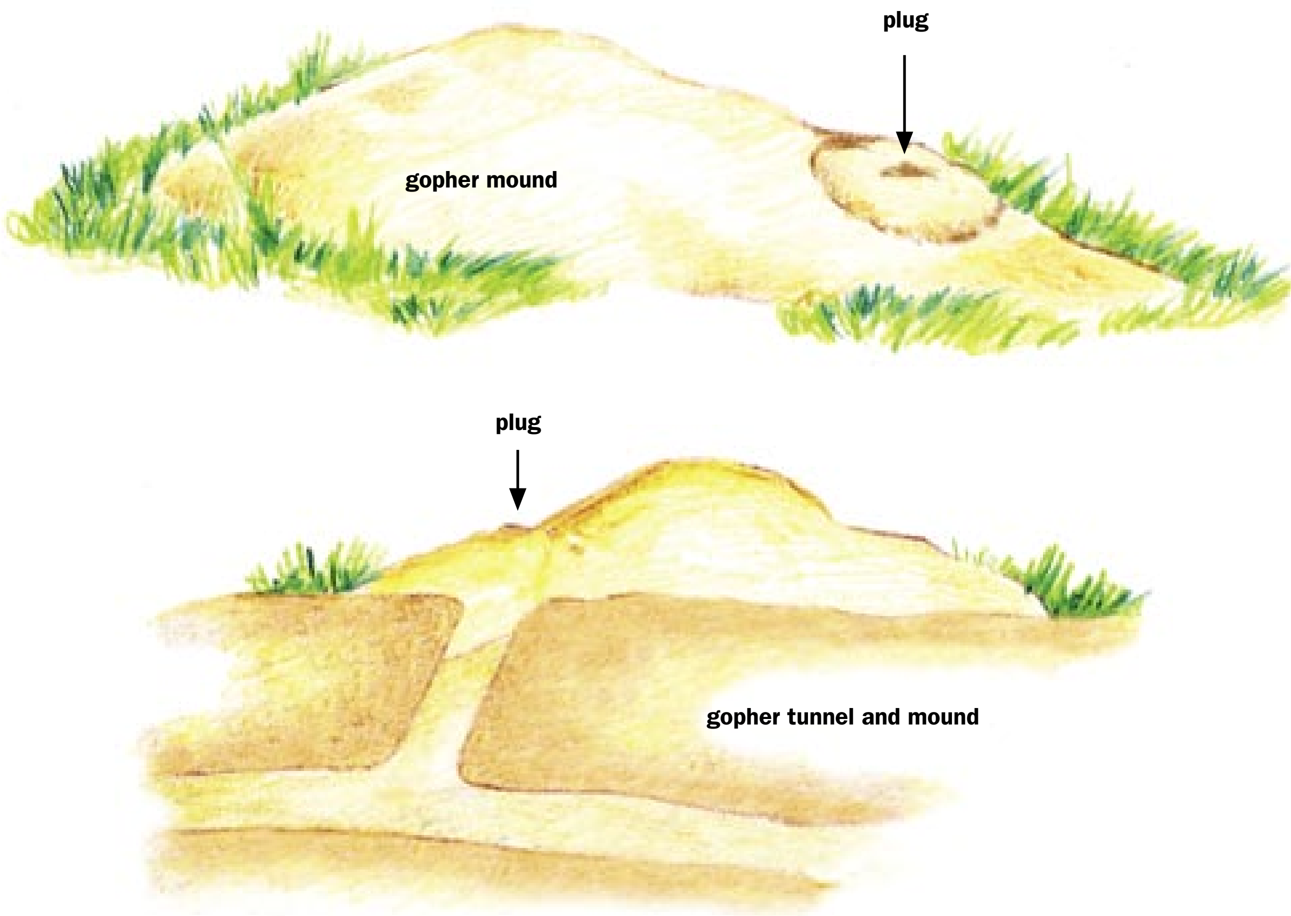


Figure 4-10. Lateral burrows of the pocket gopher end in a soil mound or a soil plug.

4.2.6 North American Badger Overview

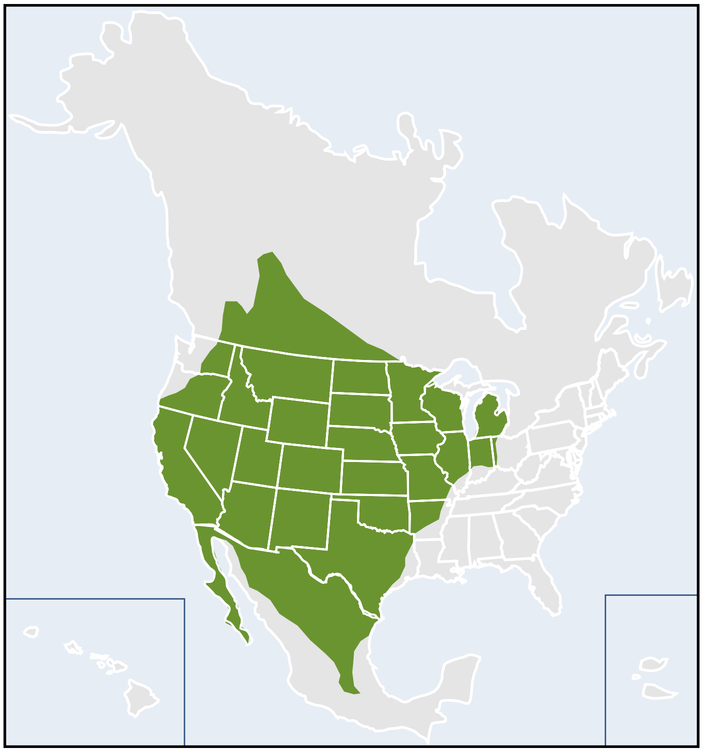
The North American Badger (Taxidea taxus) is a stocky animal that can grow up to 30 inches long. It has grayish yellow fur with pale underparts, long claws, a short, bushy tail, and black feet. Badgers can weigh from 19 to 30 pounds and can be identified by a white stripe that runs from its nose to the back of its head (University of Nebraska, 1994).

Threat to Dams: Badgers are especially adapted for digging and dig in pursuit of prey and to construct dens for shelter. Badgers can cause severe damage to hydraulic structures. Badgers can exacerbate internal and external erosion in an earthen dam by enlarging existing burrows of prairie dog, pocket gopher, or ground squirrels, all of which can inhabit an earthen dam and are a preferred food of the badger. Badger dens create large voids in the earthen dam, compromising structural integrity.

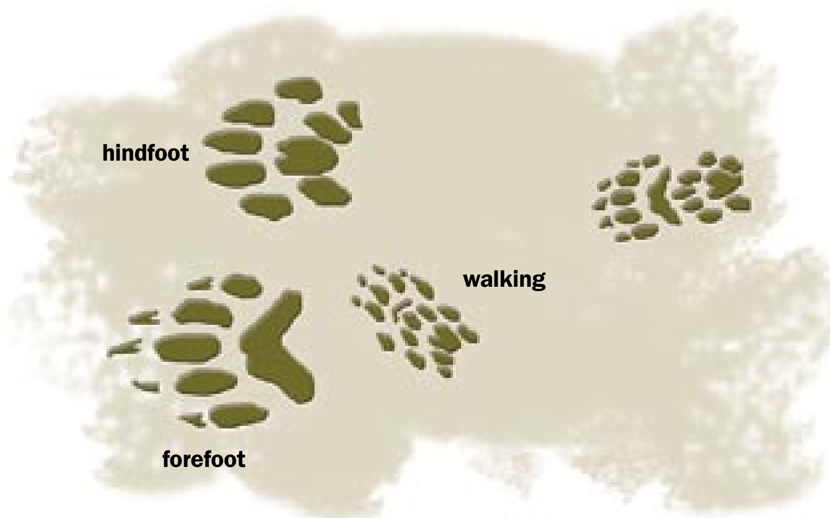
Badgers are considered a significant dam safety issue in 17% of the surveyed states.

Habitat and Home: Badgers prefer pastures or rangelands with light to moderate cover and few trees. Habitats with sandy or porous soils are preferred. Female badgers dig large burrows (5-30 feet long) with a large chamber 2-3 feet below the ground surface for birthing. Dens have one entrance that is usually elliptical in shape (University of Nebraska, 1994).

Food Habits: North American badgers are opportunist omnivores that feed on earthworms, mammals, birds, reptiles, grains, and fruits. Prairie dog, pocket gopher, and ground squirrels are common in badger diets.



Range of the badger in North America.



Badger tracks are similar to coyote tracks, but are distinct in the long claw marks on the front feet and the presence of five toes. Badger tracks are typically turned inward toward each other, and the hindprints are narrower than the foreprints.

Behavior: Badgers are adept at pursuit and capture of ground-dwelling prey. A typical burrow dug in pursuit of prey is shallow and about 1 foot in diameter (University of Nebraska, 1994). Badgers are mostly nocturnal but will be active during the day if the area is quiet. Badgers are usually solitary.

Field Tip: Large piles of dirt and rock left near animal burrows can indicate badger hunting activity. Badgers maintain the condition of their claws by sharpening them on trees or fence posts; claw marks can indicate badger presence (University of Nebraska, 1994).

Badger tunnels and dirt mounds resulting from prey pursuit can cover an area the size of a car.

4.2.7 Nutria Overview

Nutria (*Myocastor coypus*) *With an average weight of 8 pounds and a body length of 24 inches (tail is an additional 16 inches long), nutria are larger than muskrat, but much smaller than beaver. With a preferred habitat that includes permanent water, nutria are excellent swimmers with webbed hind feet, but move awkwardly on land.*

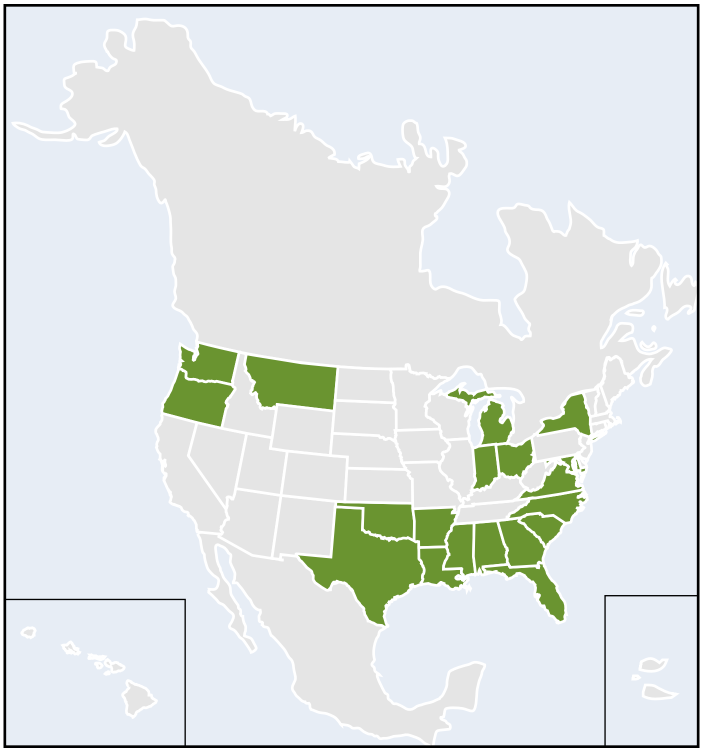
Look closely! Nutria are aquatic rodents often misidentified as either a muskrat or beaver.

Nutria are considered a significant dam safety issue in 4% of the surveyed states.

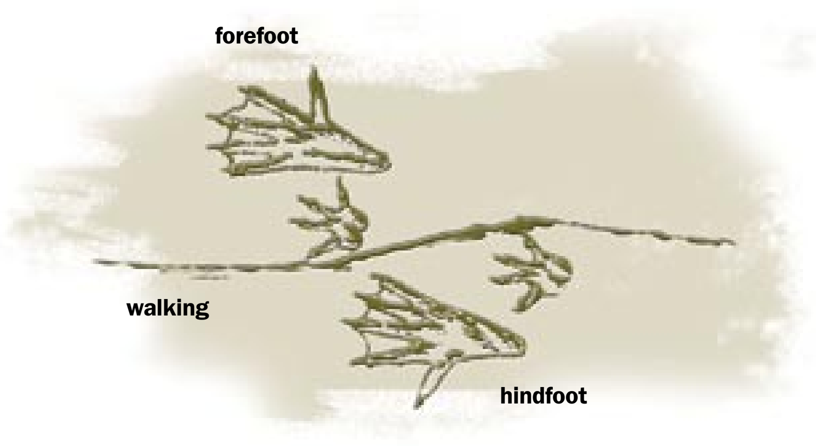
Threat to Dams: Nutria construct extensive burrows as shelter in the upstream slope. Burrows can weaken an earthen dam to the point of collapse when soil becomes saturated by precipitation or high water, or when heavy vehicles cross the crest. Nutria are notorious for breaking through water-retaining levees in Louisiana and Texas (University of Nebraska, 1994).

In some cases, nutria tunnels have been so extensive that water flowed unobstructed through the embankment necessitating its complete reconstruction.

Habitat and Home: Nutria can adapt to a variety of habitats, but prefer a semi-aquatic environment and particularly, the zone between land and permanent water. This zone is preferred for its abundance of aquatic vegetation. For the most part, any substantial nutria populations in the United States occur in freshwater marshes of coastal areas (University of Nebraska, 1994). Nutria are ground-dwellers during the summer, preferring to live in dense vegetation. The rest of the year nutria live in burrows they have dug, or that have been abandoned by armadillos, muskrat, or beaver. Nutria construct burrow entrances in vegetated banks of dams and waterways; a bank that has a slope greater than 45 degrees is a preferred location (University of Nebraska, 1994). Nutria burrows can be simple or complex; a complex burrow may have several tunnels and entrances at different levels in the bank. A burrow system will contain compartments (ranging from 1-3 feet across) for resting, feeding, and shelter from the weather and predators. Tunnels can be 4-6 feet in length.



Range of the nutria in North America.



Tracks left by nutria may also have tail drag marks, or sometimes chest marks, as a nutria may drag its chest when on land.

Food Habits: Nutria prefer aquatic plants such as sedges, rushes, cattails, and arrowheads, however the bark of black willow and bald-cypress may be eaten in the winter. Nutria eat food in a number of places including feeding platforms on the water (floating mats of vegetation or even on top of beaver and muskrat houses), in the water itself, or on land.

Behavior: Nutria feed at night when food is plentiful, but will feed during the day if food is limited. Nutria can scratch or bite aggressively if captured or cornered.

Field Tip: Unlike muskrat or beaver, a nutria's tail is round with scant hair, the whiskers are long (around 4 inches) and whitish, and nutria have prominent red-orange incisors. Trees girdled by nutria will show no teeth marks.

Nutria construct platforms of floating vegetation used for loafing, grooming, birthing, and escape, which are often mistaken for muskrat houses.

4.2.8 Prairie Dog Overview

Prairie Dogs (Cynomys spp.) are squirrel-like, burrowing rodents with squat, muscular bodies and short tails and ears. Their fur is sandy brown to cinnamon in color with grizzled black and buff-colored tips. Adult prairie dogs grow to a length of 13 to 17 inches and weigh approximately 2 to 4 pounds (USDA, 1991).

Prairie dogs are considered a significant dam safety issue in 8% of the surveyed states.

Threat to Dams: Prairie dogs dig burrows that can lead to internal erosion and structural integrity losses in earthen dams.

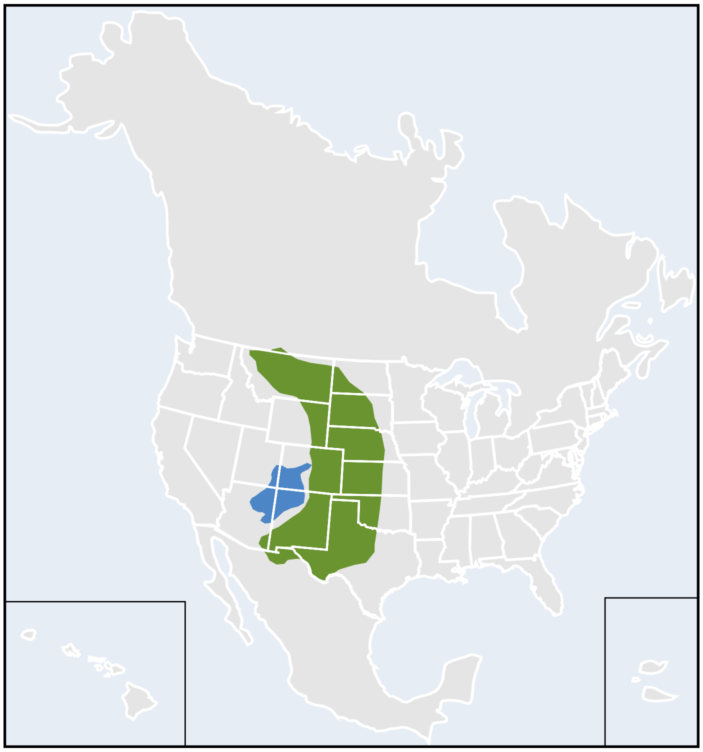
Habitat and Home: Prairie dogs prefer grassland or short shrubland habitats. They often establish colonies near intermittent streams or water impoundments (USDA, 1991). Prairie dog burrows are found in open areas with low vegetation. Their burrows are distinguished by relatively large holes and cone-shaped mounds. Prairie dogs remove the vegetation from around their burrows and use it for food or nesting material (USDA, 1991). Other animals often make their homes in prairie dog burrows, including the federally protected black-footed ferret and burrowing owl.

Food Habits: Prairie dogs eat mostly grass, although they will also eat flowers, seeds, shoots, roots, and insects when available (University of Nebraska, 1994).

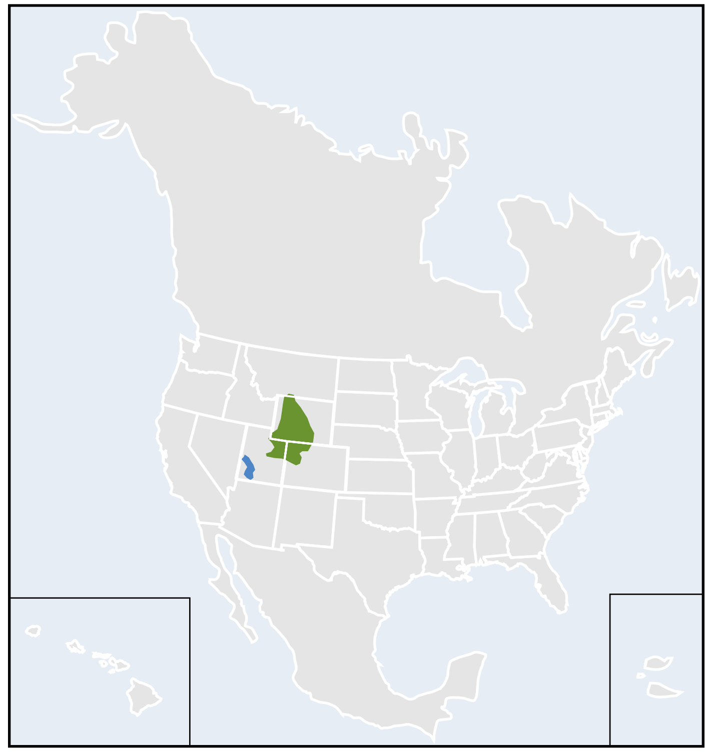
Behavior: Prairie dogs live in large colonies known as "towns." Each town is made up of a complex series of tunnels and may have as many as 20 to 50 burrow entrances. Prairie dogs are social animals that are most active during the day (University of Nebraska, 1994).

Field Tip: Look for mounds of earth about 1 to 2 feet high that resemble miniature volcanoes.

Range of the prairie dog in North America.



Black-Tailed (Cynomys ludovicianus), and Gunnison (Cynomys gnnisoni) prairie dogs



White-Tailed (Cynomys leucurus), and Mexican (Cynomys mexicanus) prairie dogs

Prairie dog tracks will show five toes on the hindfoot and four toes on the slightly smaller forefoot.

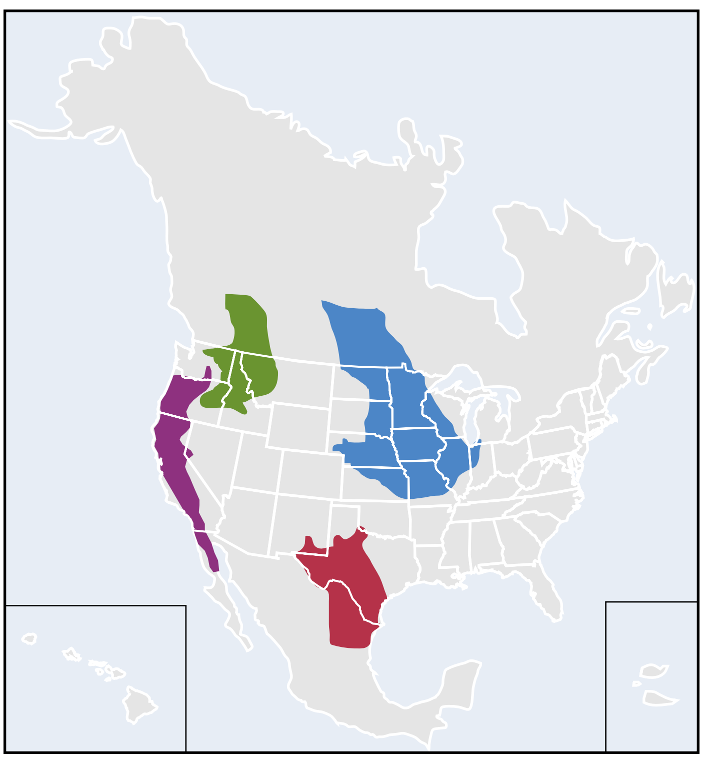
4.2.9 Ground Squirrel Overview

Ground Squirrel (Spermophilus spp.) are small to medium-sized burrowing rodents. Twenty-three species of ground squirrels live in the United States (University of Nebraska, 1994). They vary is size, with lengths ranging from 6 to 20 inches and weight ranging from 0.25 to 2.5 pounds. They also vary in color, ranging from brown to reddish brown to gray. Some species have markings, such as spots or stripes. Some species have long bushy tails, while others have short tails with short hair (USDA, 1991).

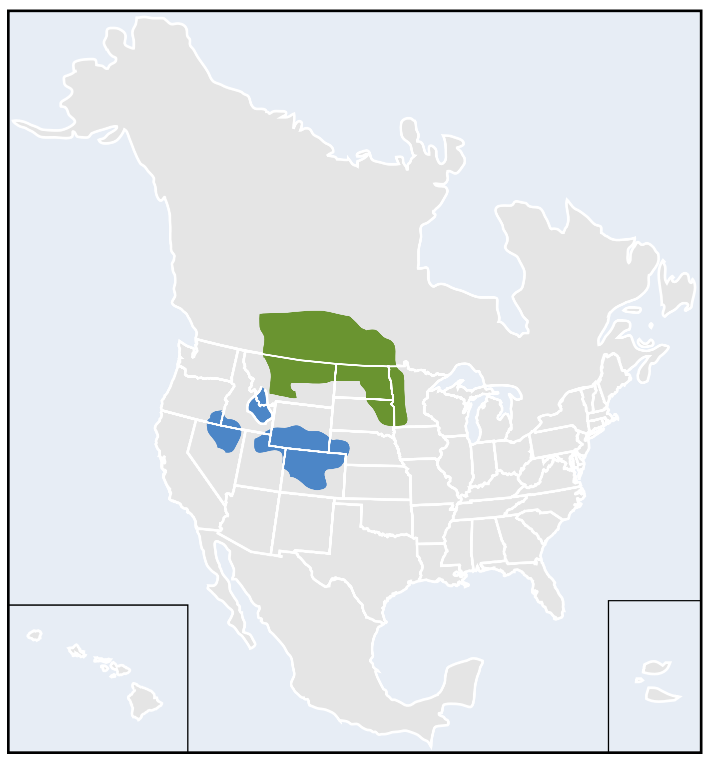
Threat to Dam: Ground squirrels dig burrows that can lead to internal erosion and structural integrity losses in earthen dams. The presence of ground squirrels also increases the likelihood of badger activity. Badgers will pursue ground squirrels into their burrows, which can be very destructive to earthen dams (USDA, 1991).

Habitat and Home: Ground squirrels can be found in at least 27 states west of Ohio. They occupy a wide range of habitats from low coastal areas to mountains. Ground squirrels keep their burrows unplugged. Specific burrow design varies with species, soil type, habitat and climate. Some species of ground squirrels are colonial, which means that several individuals live in the same burrow system. These systems consist of clustered, above-ground mounds that resemble prairie dog burrows. They are generally easier to spot than the burrows of solitary ground squirrel species, which tend to be scattered and inconspicuous (USDA, 1991).

Range of the ground squirrel in North America.

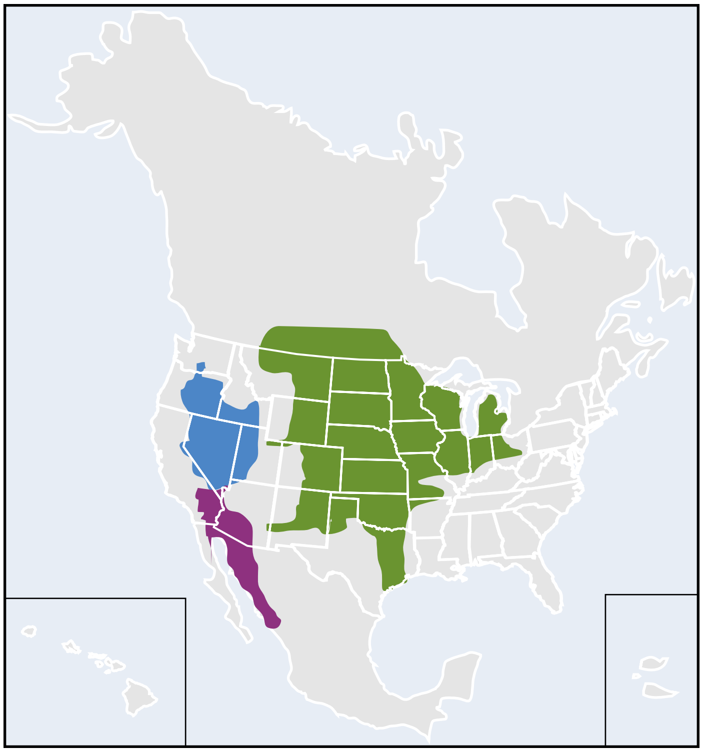


Columbian (Spermophilus columbianus), Franklin (Spermophilus franklinii), California (Spermophilus beecheyi), and Mexican (Spermophilus mexicanus), ground squirrels

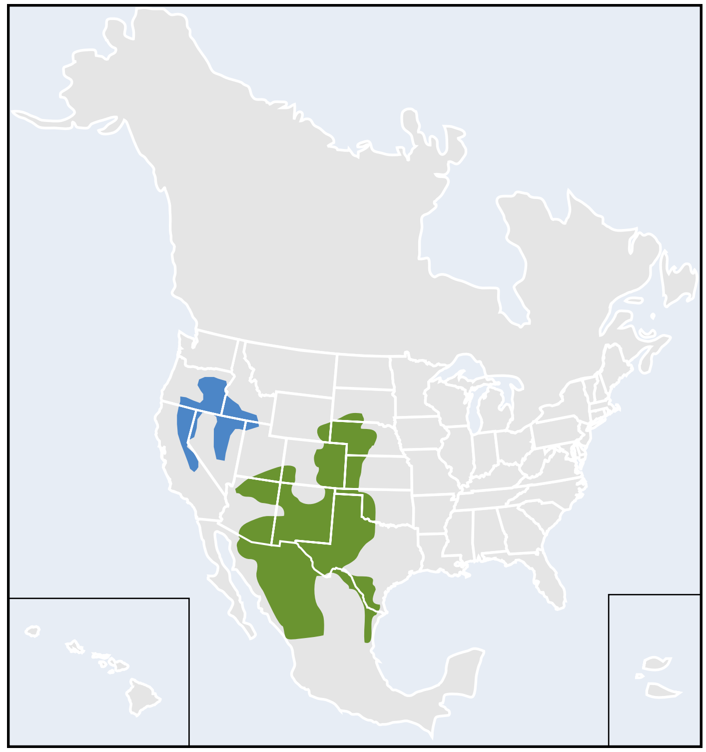


Richardson (Spermophilus richardson), and Wyoming (Spermophilus elegans) ground squirrels

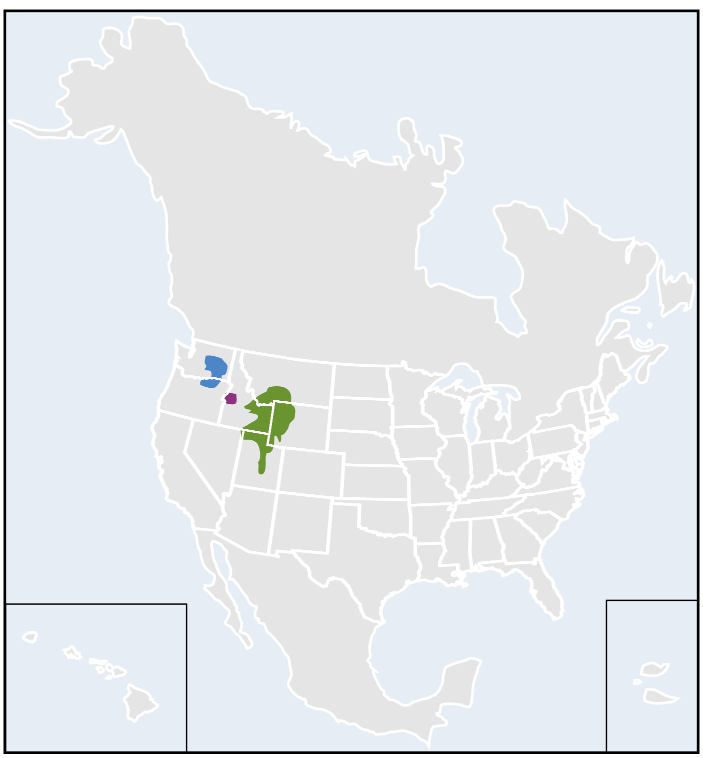
Range of the ground squirrel in North America (continued).



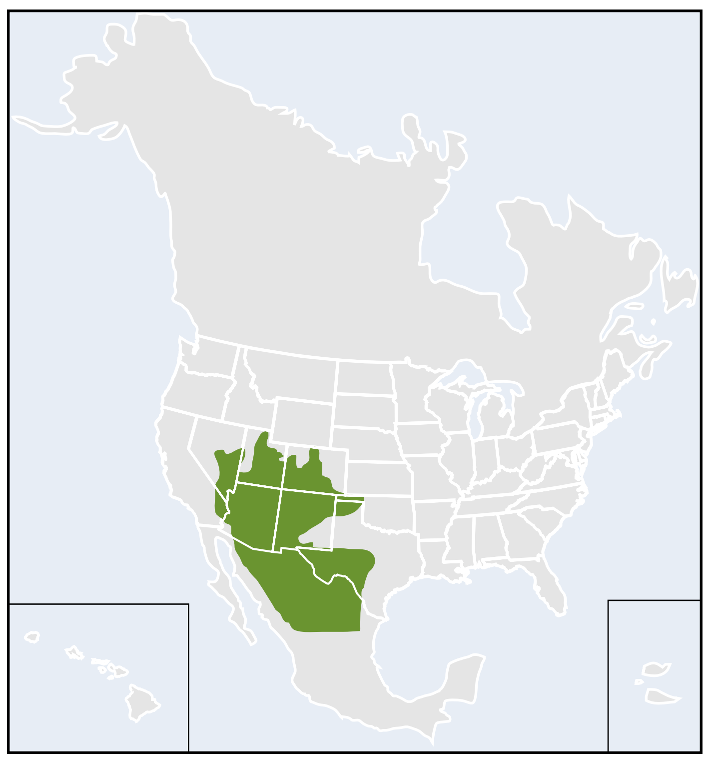
Townsend (Spermophilus townsendi), Thirteen-lined (Spermophilus tridecemlineatus), and Round-tailed (Spermophilus tereticaudus) ground squirrels



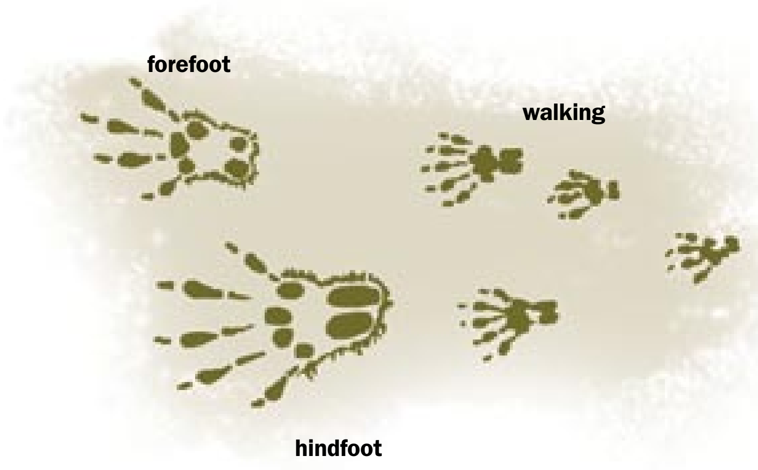
Belding (Spermophilus beldingi) and Spotted (Spermophilus spilosoma) ground squirrels



Washington (Spermophilus washingtoni), Idaho (Spermophilus brunneus), and Uinta (Spermophilus armatus) ground squirrels



Rock (Spermophilus variegatus) ground squirrels



Although ground squirrel tracks will vary in size, they generally show five toes on the hindfoot and four toes on the smaller and rounder forefoot.

Food Habits: Ground squirrels mostly eat plant material, although some species may also eat insects, eggs, carrion, and other animal material (USDA, 1991).

Behavior: Ground squirrels are only active during the day, and they are most active during mid-morning and late afternoon. They hibernate in the winter, and most species estivate in summer as well (USDA, 1991).

Field Tip: During warm months, ground squirrels are quite active during the day and can be easily spotted. Unplugged burrows are a distinctive characteristic of ground squirrel inhabitation (USDA, 1991).

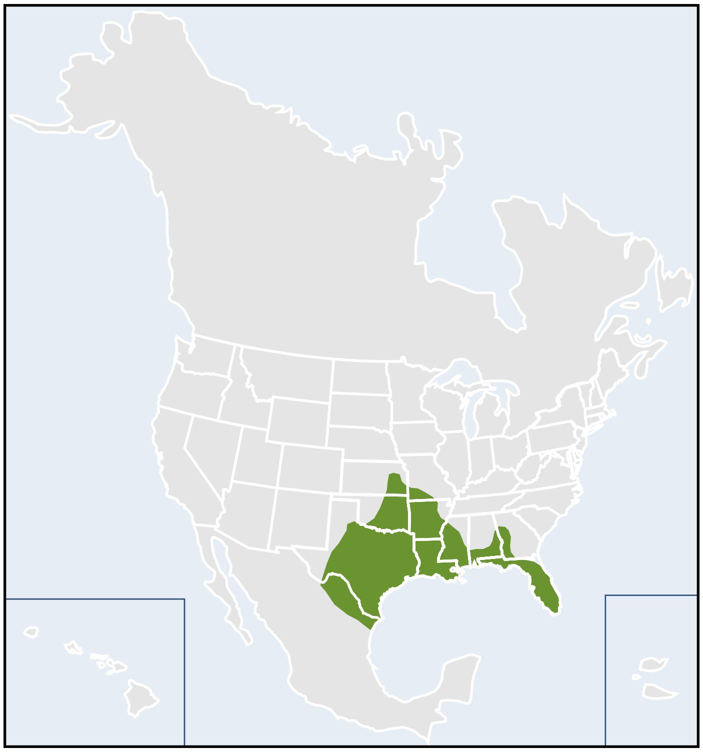
Ground squirrels are considered a significant dam safety issue in 15% of the surveyed states.

4.2.10 Armadillo Overview

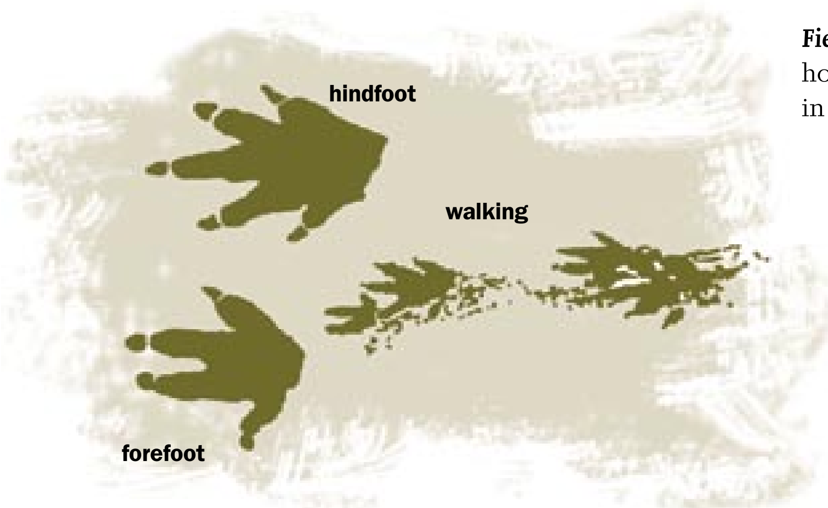
The Armadillo (Dasypus novemcinctus) is a medium-sized animal, about 8 to 17 pounds, with a protective, armor-like shell on its head, body, and tail. It has nine movable bands across its back, and the tail is covered with a series of overlapping rings. The armadillo has a small head with a long, narrow, piglike snout (University of Nebraska, 1994).

Threat to Dams: Armadillos dig burrows that can result in internal erosion and structural integrity losses in dams.

Habitat and Home: It prefers forest, woodland and brush habitat, as well as areas near creeks and rivers. The armadillo will also inhabit areas with rocks, cracks, and crevices that are suitable for burrows (University of Nebraska, 1994). Armadillos generally dig burrows 7 to 8 inches in diameter and up to 15 feet in length. They can be found in rock piles, around stumps, brush piles, or terraces around brush or dense woodlands. Armadillos usually have more than one den in an area (University of Nebraska, 1994).



Range of the armadillo in North America.



Armadillos have four toes on their forefeet and five toes on their hindfeet, although not all toes may show up in their tracks. Sharp claw marks are often visible.

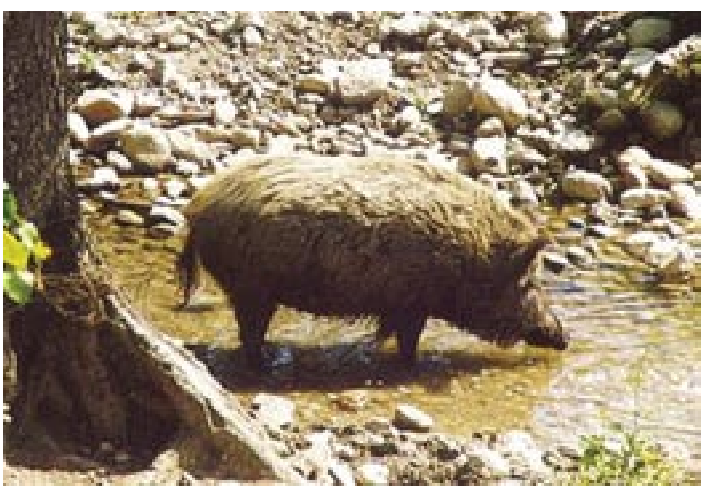
Food Habits: The armadillo primarily eats insects and their larvae. They also feed on spiders, earthworms, scorpions, and other invertebrates. To a lesser extent, they may eat some fruit and vegetable matter (University of Nebraska, 1994).

Armadillos are considered a significant dam safety issue in 4% of the surveyed states.

Behavior: During the summer, the armadillo is active from twilight through early morning hours, but in the winter, it is usually only active during the day. The armadillo has poor eyesight, but a keen sense of smell. It can run fast when in danger and is also a good swimmer (USDA, 1991).

Field Tip: Characteristic signs of armadillo activity are shallow holes, about 1 to 3 inches deep and 3 to 5 inches wide, dug in search of food (University of Nebraska, 1994).

4.2.11 Livestock Overview



Livestock can include cattle, horses, sheep, goats, and pigs of all varieties, domesticated and wild. Livestock exist widely across the United States and utilize earthen dams and farm ponds for grazing and drinking.

Threat to Dams: Livestock can damage an earthen dam by removing stabilizing vegetation through grazing, trampling, and rooting. External erosion can occur without vegetative cover, and erosion pathways can be created as livestock traverse the embankment (Figures 4-11 and 4-12). Damages are most severe in arid regions, and damage is often not noted until the wet season when precipitation collects in holes and along erosion pathways. Livestock carcasses could alter or block water flow if located at control structures. Wild pigs commonly damage farm ponds and can cause substantial damage to a grassy area in a single night (University of Nebraska, 1994).

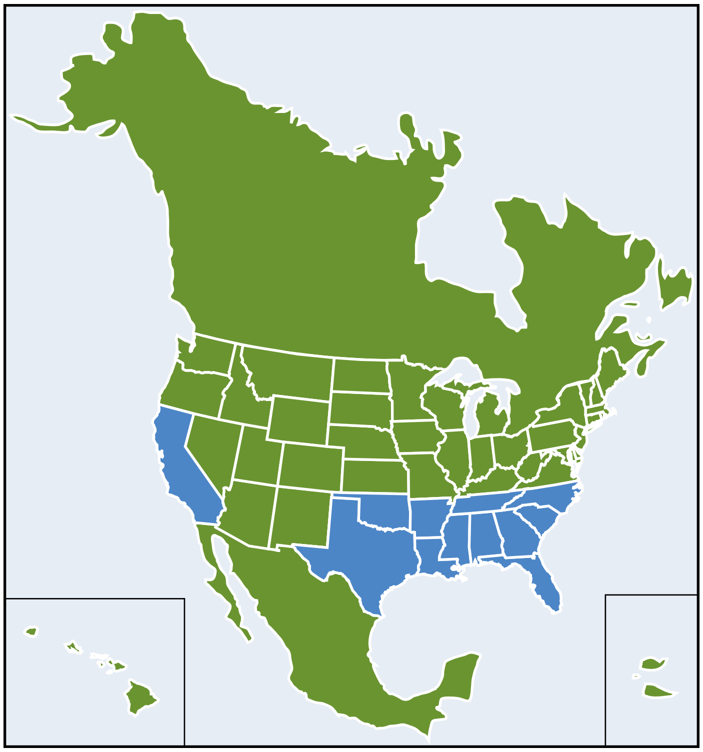
Livestock are considered a significant dam safety issue in 25% of the surveyed states.

Habitat and Home: Livestock can occur anywhere in the United States. In some cases, several livestock species will graze in one area. Wild pigs can exist in a variety of habitats but prefer dense brush or marsh vegetation as cover. Wild pigs are often found inhabiting livestock-producing areas (University of Nebraska, 1994).

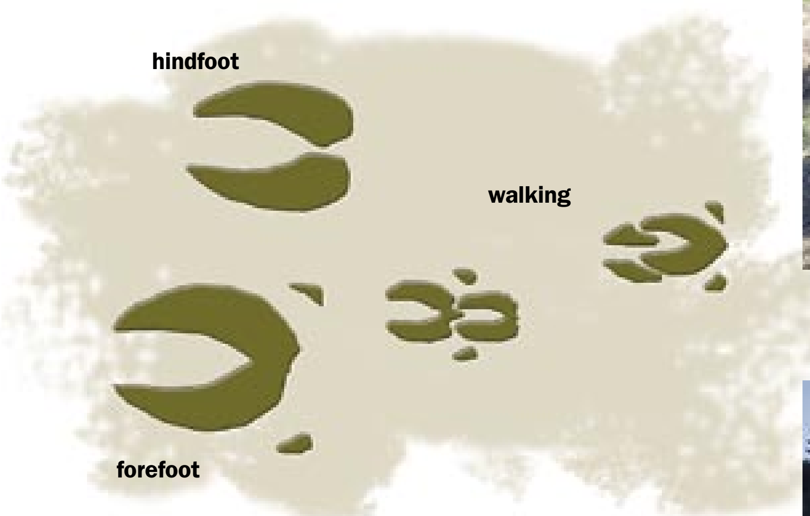
Food Habits: Most livestock, including cows, sheep, goats, and horses, are grazers. Pigs, however, generally root for underground vegetation, in addition to feeding on acorns and other mast. Livestock disturb soil and vegetation through their feeding methods.

Behavior: Location to a water source is considered the primary influence on livestock's activity within a given grazing area, followed by desirable forage and topography of the grazing area. In hot weather, pigs will wallow in ponds, springs, or streams that contain or are near vegetative cover.

Field Tip: Livestock are easily identified as they are often intentionally grazed on lands near farm dams. Wild pigs are obvious if observed, otherwise look for wallows.



Range of livestock, and wild pigs in North America.



Tracks can be used to identify wild pigs. Tracks are generally not needed to identify other types of livestock since they are often intentionally grazed on lands near farm dams.

One milk-producing Jersey cow can drink up to 12 gallons of water a day. Herds of dairy cows typically include 50 to 100 animals. That's a lot of hoof-traffic at an earthen dam!

Figure 4-11. Livestock can cause external erosion by creating ruts and erosion paths via hoof traffic.

Figure 4-12. Livestock can remove stabilizing vegetation through grazing and hoof traffic.

4.2.12 Crayfish Overview

Crayfish (Cambarus spp.) resemble miniature lobsters. There are over 300 species of various sizes, shapes, and colors in the United States (University of Nebraska, 1994).

Threat to Dams: Crayfish burrow into earthen dam embankments; extensive burrowing may cause internal erosion and structural integrity losses.

Habitat and Home: Crayfish are found in a variety of fresh water habitats, including streams, rivers, ponds, lakes, swamps, and wet meadows (Peckarsky et al, 1990). Crayfish burrows are usually located along the shoreline close to the water's edge. They may be anywhere from a few inches to three feet deep. The opening is generally about ¼ to 2 inches in diameter with a cone-shaped mound, known as a "chimney," plugging the burrow (Virginia Cooperative Extension, 2001a) (Figure 4-13).

Food Habits: Crayfish eat both living and dead plant and animal material. Almost half of their diet consists of bottom-dwelling worms and insects. The rest of their diet consists of

Crayfish are considered a significant dam safety issue in 4% of the surveyed states.

Figure 4-13. A crayfish burrow is a cone-shaped mound or "chimney" made with mud pellets.

Range of the crayfish in North America.

living and decaying aquatic vegetation (Virginia Cooperative Extension, 2001a).

Behavior: A crayfish will molt several times in its short lifespan. They can be quite aggressive towards each other and toward anything they perceive as a threat (Peckarsky et al, 1990). Most crayfish dig burrows to use as a refuge from predators and as a resting place during molting and inactive periods (Virginia Cooperative Extension, 2001a).

Field Tip: Crayfish stay in their burrows or in mud bottoms during cold weather. They will emerge, and be easier to spot, once the water warms up (Virginia Cooperative Extension, 2001a).

4.2.13 Coyote Overview

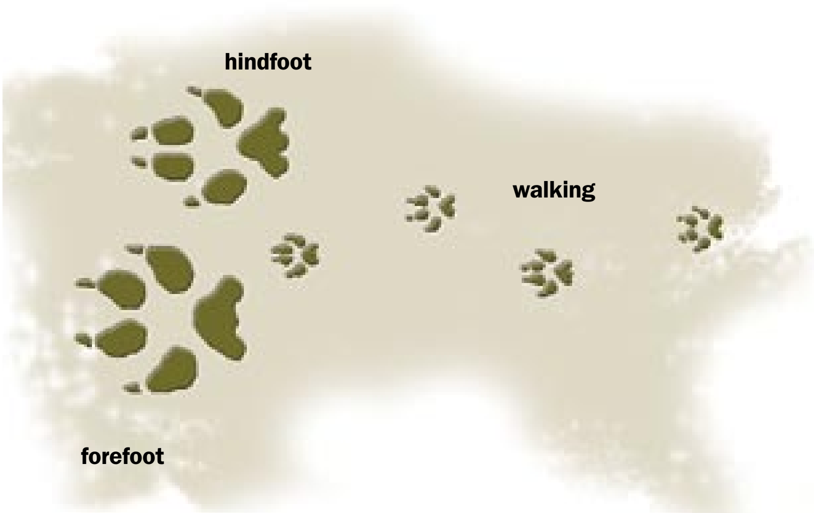
The Coyote (Canis latrans) is a member of the dog family, and in size and shape, it resembles a small German shepherd, with erect pointed ears, slender muzzle, and a bushy tail. Coyotes are generally brownish-gray with a lighter colored belly, although this varies widely across local populations. In the west, adult males typically weigh 25 to 45 pounds and adult females typically weigh 22 to 35 pounds. Coyotes in the east are usually larger, with adult males weighing about 45 pounds and adult females weighing about 30 pounds (University of Nebraska, 1994).

Threat to Dams: Although coyotes do not pose a large threat to earthen dams, den construction or enlargement, and digging out prey that live at the dam can cause structural integrity losses.

Coyote are considered a significant dam safety issue in 4% of the surveyed states.

Habitat and Home: Coyotes exist in virtually any type of habitat, arctic to tropic. High densities of coyotes even appear in the suburbs of major western cities such as Los Angeles and Phoenix. Their dens are often found in steep banks, rock crevices, sinkholes, and underbrush, as well as open areas. Dens are usually located close to water. Coyotes will often dig out and enlarge burrows of other animals. Size of coyote dens varies from a few feet to 50 feet, and each den often has several openings (University of Nebraska, 1994).

Range of the coyote in North America.



Badger tracks are often confused with coyote tracks, but note that coyotes only have four toes on each foot, while badgers have five toes.

Food Habits: Coyotes eat a variety of animals, insects, fruits, and vegetables (University of Nebraska, 1994).

Behavior: During hot summer months, coyotes are most active at night and during the early morning hours. During cooler weather, and in areas with minimal human activity, coyotes may be active throughout the day. Coyotes have good eyesight and hearing and a keen sense of smell. Their adaptable behavior and social system allows them to survive, and even flourish, in the presence of humans (University of Nebraska, 1994).

Field Tip: Coyotes can often be identified by their tracks, although it should be noted that regular dog tracks are often mistaken for coyote tracks. Coyote dens are often located in the downstream slope.

4.2.14 Moles and Voles Overview

Moles (Scapanus spp.) are small insectivores that are often confused with voles, shrews, and pocket gophers. Moles, however, can be distinguished by their hairless, pointed snout, small eyes, and webbed forefeet. There are seven different species of moles living in the United States. Adult males grow to a length of about 7 inches and weigh about 4 ounces; adult females are slightly smaller (University of Nebraska, 1994).

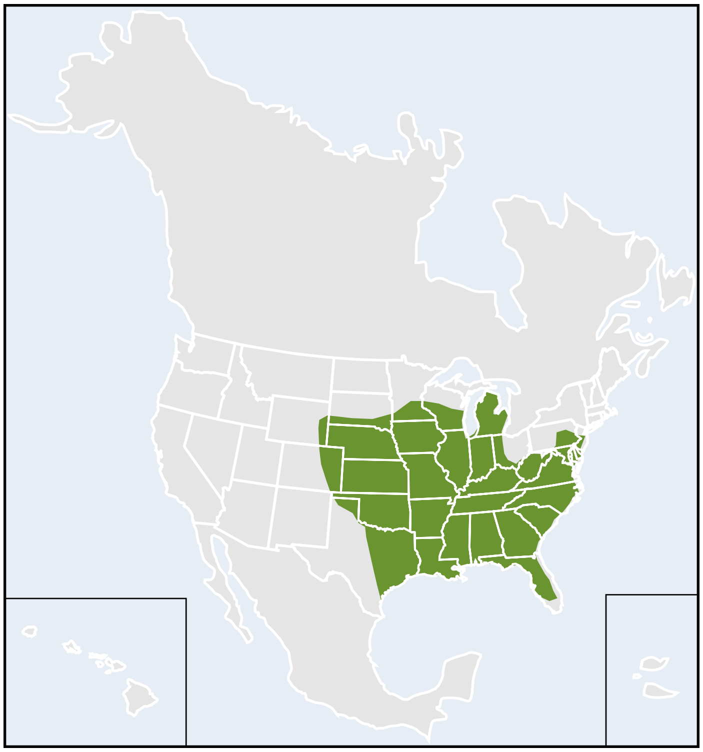
Voles (Microtus spp.) also known as meadow mice or field mice, are compact rodents with short legs and short tails. There are 23 species of voles in the United States. Most are gray or brown, and about 4 to 8 inches long; although both size and coloration varies across species.

Threat to Dams: Earthen dams may provide good hunting grounds for moles. Although they usually make their home burrows in dry, upland areas, they prefer to hunt in areas that are cool and moist. They construct tunnels from their dens to their hunting grounds. If located in an earthen dam, these tunnels may cause internal erosion and structural integrity losses. When present in large numbers, voles may also cause damage to earthen dams. They dig extensive burrow systems that could lead to internal erosion and structural integrity losses in the dam (University of Nebraska,1994).

Moles and voles are considered a significant dam safety issue in 10% of the surveyed states.

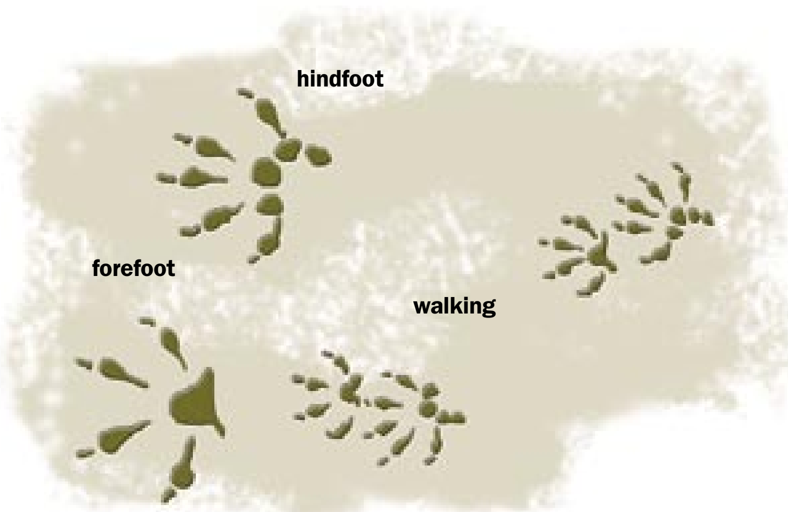
Habitat and Home: Moles can be found across most of the United States. As mentioned above, they generally construct their burrows in dry, upland areas. Deep runways connect their dens to their hunting grounds (University of Nebraska, 1994) (Figures 4-14 and 4-15, shown on page 51). Voles can also be found across most of the United States. They prefer areas of heavy ground cover, although they can survive in a wide variety of habitats. Burrow systems consist of a series of tunnels and surface runways, and often have several entrances (University of Nebraska, 1994) (Figure 4-16, shown on page 51).

Food Habits: Moles primarily eat insects, grubs, and worms. Voles are mostly herbivorous, primarily eating grasses and forbs. Voles will also occasionally eat snails, insects, or animal remains (University of Nebraska, 1994).



Range of the mole in North America.

Range of the vole in North America.



Vole tracks.

Behavior: Moles are solitary animals, and they spend most of their time underground. They are active through all seasons of the year. Voles are also active throughout the year, both day and night. They are excellent swimmers and often try to escape from predators through the water (University of Nebraska, 1994).

Field Tip: Moles push up volcano-shaped mounds of soil when they are building tunnels. The mounds may be anywhere from 2 to 24 inches tall. Surface tunnels or ridges are also an indication of mole activity. Voles can be identified by their extensive surface runway systems. These runways are generally 1 to 2 inches in width.

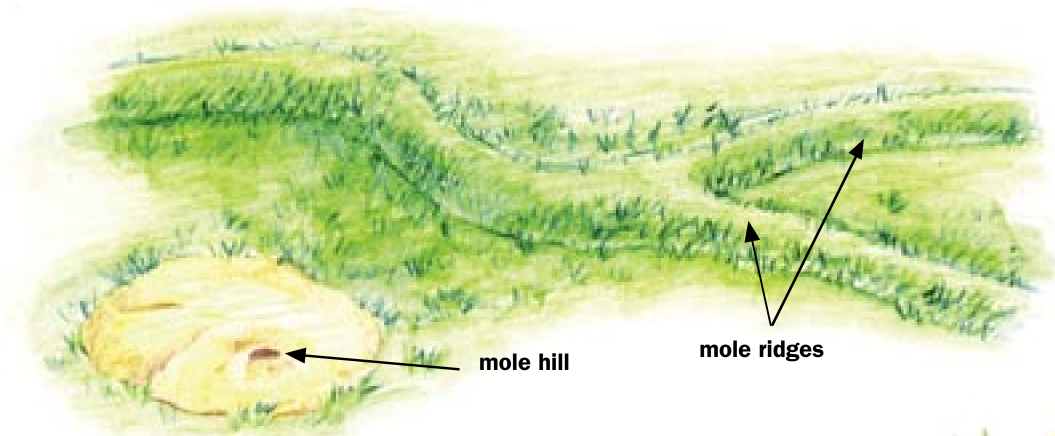


Figure 4-14. Mole burrows form ridges visible from the surface.

Figure 4-15. Moles push dirt vertically to the surface, which forms a mound.

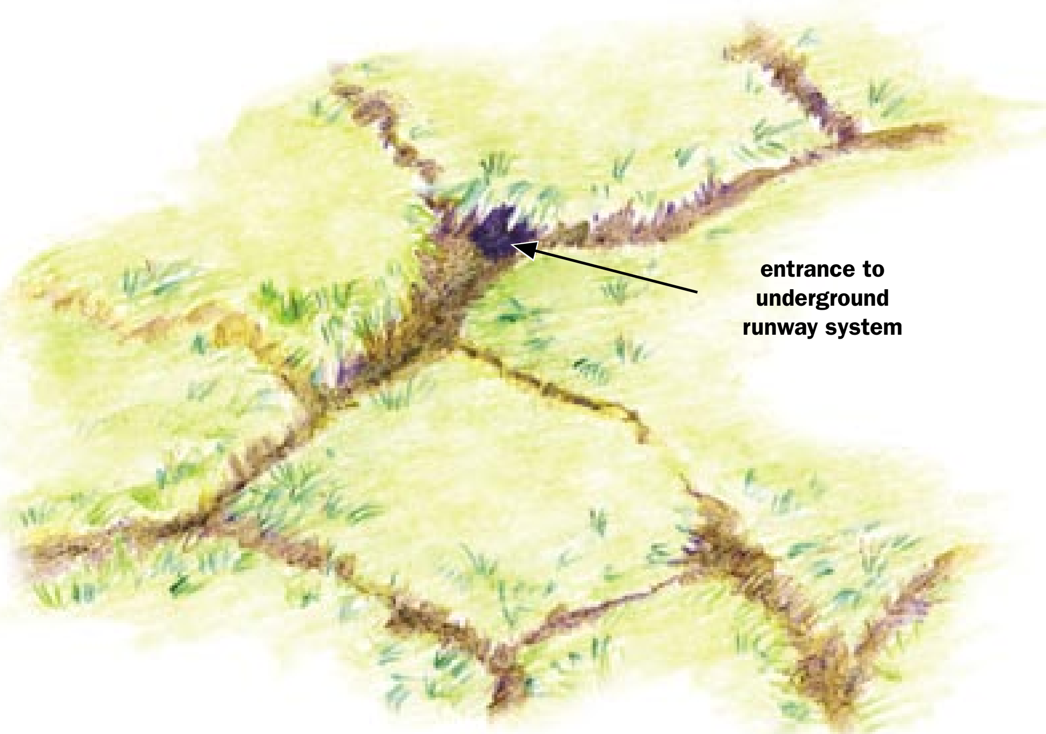


Figure 4-16.Voles are most easily identified by an extensive surface runway system with many burrows.

4.2.15 River Otter Overview

The River Otter's (Lutra canadensis) sleek body, short legs, webbed toes, and tapered tail help it thrive in its aquatic environment. Otter fur is thick and shaded from brown to near black on most of the body, with a lighter brown to beige on the belly, chin, throat, cheeks, and chest (University of Nebraska, 1994).

River otters are considered a significant dam safety issue in 4% of the surveyed states.

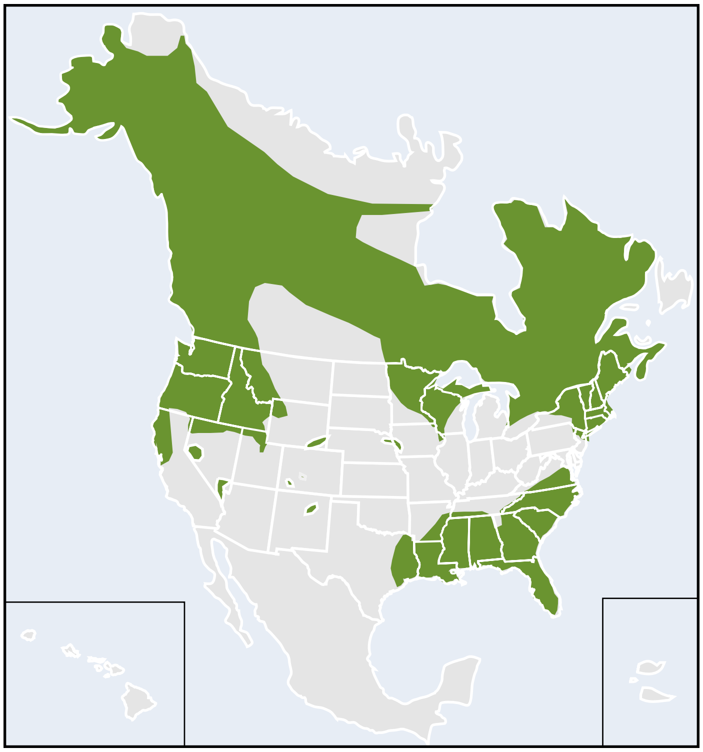
Threat to Dams: Otters sometimes dig bank dens for shelter with an underwater entrance for use in the winter and an above-water entrance for use in the summer (Benyus, 1989). Dens can cause large voids in the dam embankment, and underwater entrances provide pathways for internal erosion and wave action if water levels rise into the embankment den.

Habitat and Home: Otters are associated almost invariably with water environments no matter the water type: fresh, brackish, or salt. Water quality, available fish forage, and available den sites are the most important factors in determining otter habitat. Otters can be found in lakes, rivers, streams, bays, estuaries and associated riparian habitat. Otters most often utilize existing bank dens and lodges constructed by beaver, muskrat, and nutria. Otherwise, otters use hollow logs and rock crevices as their shelter and construct natal dens on small streams that lead to major drainages (University of Nebraska, 1994).

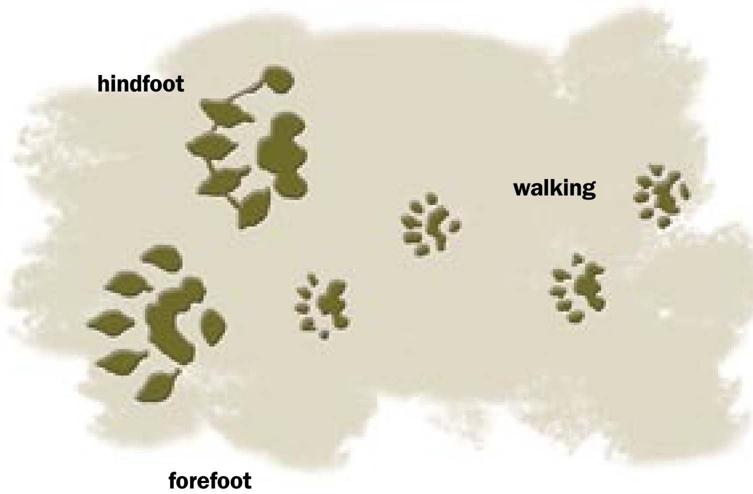
Food Habits: Otters prefer fish of several varieties, but also feed on shellfish, crayfish, reptiles, and amphibians.

Behavior: Otters spend most of the day feeding and participating in group play. Otters are superb swimmers and very alert.

Field Tip: Look for slides into the water or snowbank (in winter) where otters play. Look for "haul-outs," worn areas along the bank where otters consistently pull themselves out of the water. If this area is indeed a haul-out, there will be a trail leading away from the haul-out to a patch of trampled vegetation where otters roll around to dry themselves after a swim or to leave their scent (Benyus, 1989). Listen for the blow and sniff sounds of a surfacing otter.



Range of the river otter in North America.



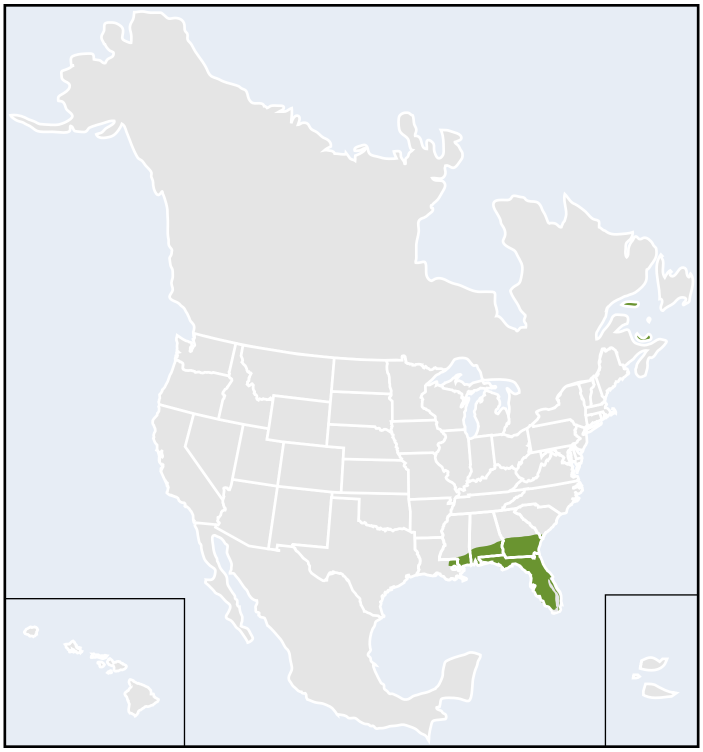
The inner toe of the otter's hind paw juts out to the side.

4.2.16 Gopher Tortoise Overview

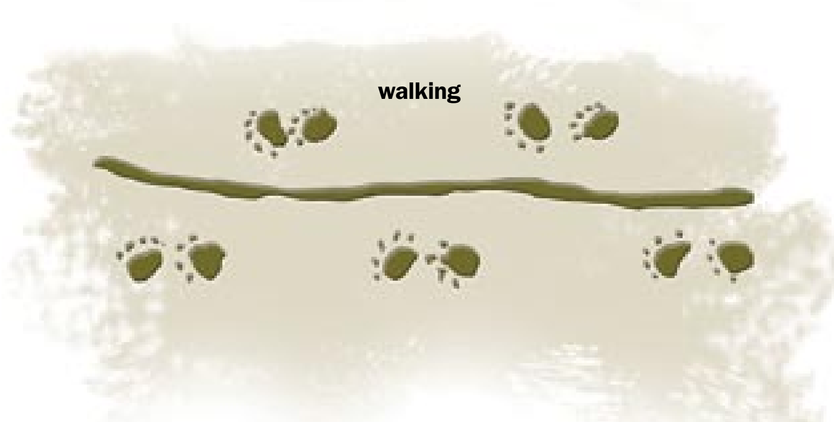
Gopher Tortoise (Gopherus polyphemus) are large, terrestrial tortoises with a shell length of 10 to 15 inches that weigh about 9 pounds. The gopher tortoise is a protected species and a permit is always required to possess, study, remove, or relocate a specimen (Gopher Tortoise Council, 2001). The burrows of the gopher tortoise are also protected by law. Over 360 animal species have been documented inhabiting a gopher tortoise burrow so use caution when investigating a burrow. Many of the species which coexist in or use gopher tortoise burrows are also protected by state and federal laws, such as the burrowing owl and indigo snake.

Threat to Dams: The gopher tortoise's strong claws make it an effective burrower. Burrows can be 40 feet long and 10 feet deep and will include a spacious chamber used to cool off during the heat of the day (Gopher Tortoise Council, 2001). Gopher tortoise burrows can cause structural integrity losses.

Tortoises are considered a significant dam safety issue in 4% of the surveyed states.



Range of the gopher tortoise in the United States.



The shell of the gopher tortoise may obliterate some of the track as it drags.

Habitat and Home: Gopher tortoises prefer to dig their burrows in dry, upland habitats especially where saw-palmetto is present in the understory and sandy soils dominate. Gopher tortoises can live in grassy areas, pastures, and old fields as long as there are well-drained sandy soils, herbaceous plants, and sunny, open areas for nesting and basking (Gopher Tortoise Council, 2001). Look for burrows on the southeastern side of sandy hills (such as old dunes that are covered in vegetation) at a 30-degree angle from the surface (Benyus, 1989; Enchanted Forest Nature Sanctuary, 2003). The burrow entrance, or "apron," will be marked by a characteristic mound of loose sand. The downstream slope and toe of a dam may be suitable for gopher tortoises, as might a forest fringe in a dam area.

Note: In some cases, snapping turtles may hibernate or lay eggs in an existing muskrat den and as such, are often identified as the responsible burrowing animal. In truth, turtles are more correctly simply associated with burrowing animals, rather than responsible for burrows. Depending on its size, the snapping turtle may enlarge an existing muskrat den.

An east-central Florida study indicates that a male gopher tortoise constructs and uses an average of 17 burrows. Some males construct and use as many as 35 burrows.

Food Habits: Primary food sources of the gopher tortoise include low-growing grasses, herbs, and berries.

Behavior: Gopher tortoises emerge from their burrows in the morning to feed and return to the burrows if temperatures get too hot or cold.

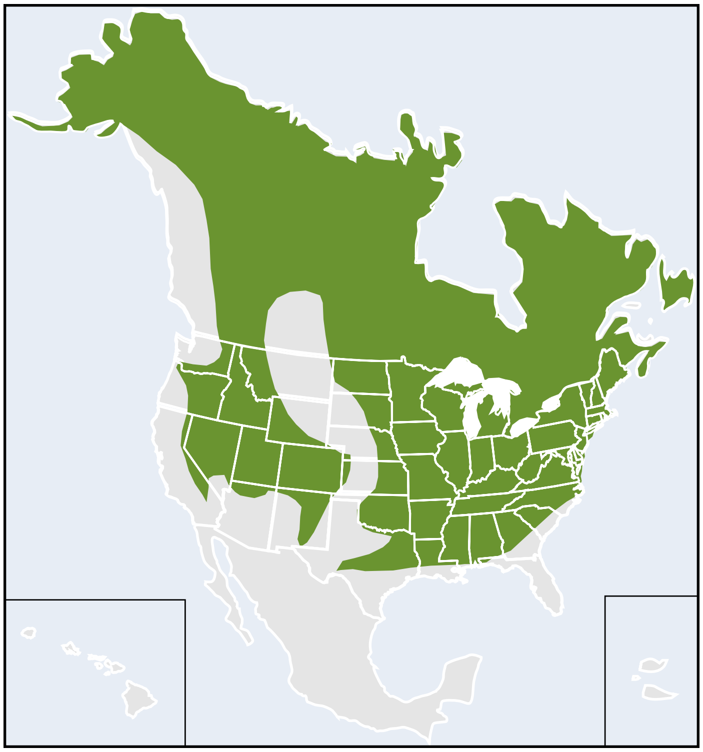
Field Tip: Look for large mounds of loose sand created as the gopher tortoise digs its burrow.

4.2.17 Red Fox and Gray Fox Overview

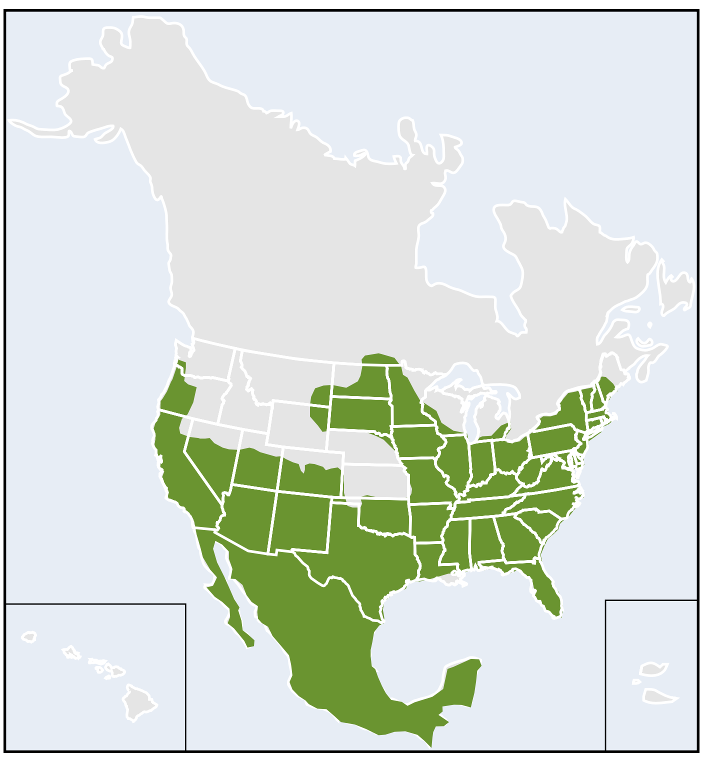
The Red Fox (Vulpes vulpes) is dog-like in appearance with large pointed ears and an elongated pointed muzzle. It typically has a light orange-red coat with lighter colored underfur, black legs, and a white-tipped tail. Coat coloration can vary from red to gray to black, but the tail tip is always white. Adult red foxes can weigh anywhere from 7.7 to 15.4 pounds; males are about 2.2 pounds heavier than females (University of Nebraska, 1994).

The Gray Fox (Urocyon cinereoargenteus) has a long, bushy tail with a black tip. It is salt-and-pepper gray over most of its body, with some rusty yellow spots on the sides of the neck, back of the ears, legs and feet. Adult gray foxes weigh about 7 to 13 pounds, and measure about 32 to 45 inches from nose to tip of tail (University of Nebraska, 1994).

Fox are considered a significant dam safety issue in 4% of the surveyed states.



Range of the red fox in the North America.



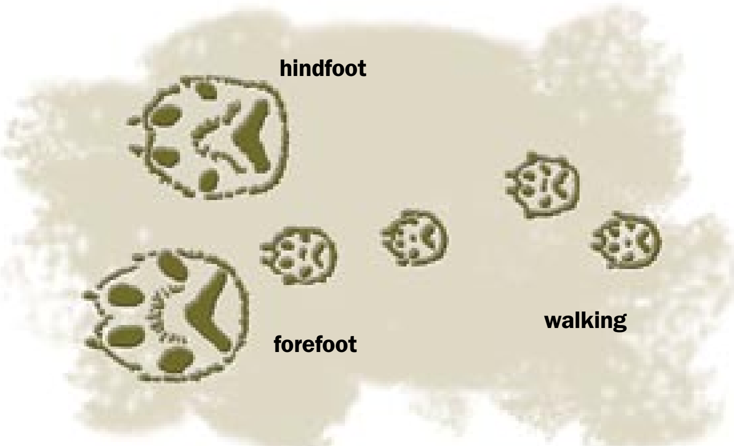
Range of the gray fox in North America.

Threat to Dams: Foxes do not pose a great threat to earthen dams. It is possible that they could cause damage by digging out burrowing animals for food. This type of damage may be prevented with good rodent control and vegetative management.

Habitat and Home: The red fox prefers open country with moderate cover, although it is generally adaptable to any habitat within its range. Red foxes are commonly found in urban areas. They may either dig their own dens or use abandoned groundhog or badger burrows. The gray fox prefers areas of dense cover such as swamp land or thickets. Gray foxes can also be found in urban areas. They commonly use wood piles, rocky outcrops, or hollow trees as den sites (University of Nebraska, 1994).

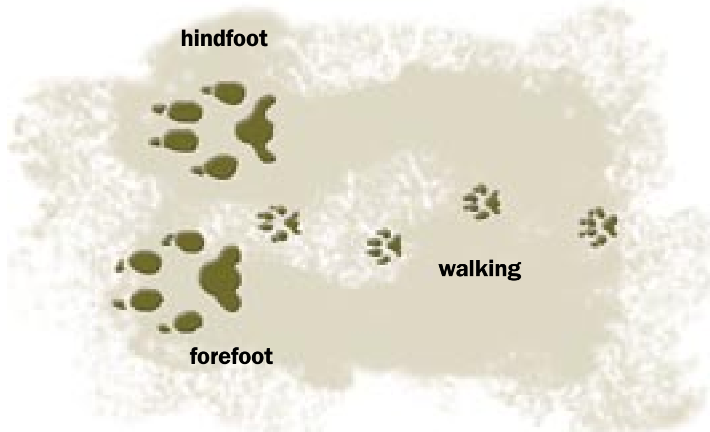
Food Habits: Foxes mostly eat rabbits, mice, bird eggs, insects, and fruit (University of Nebraska, 1994).

Behavior: Foxes are solitary animals that are most active during twilight and early morning hours. They have a variety of calls that sound like barks, screams, howls, yaps, growls, and hiccups (University of Nebraska, 1994).



Tracks of red fox.

Field Tip: Fox dens may be identified by several 10-inch wide entrance holes, with sandy aprons of soil spilling from them (Benyus, 1989).



Tracks of gray fox.

4.2.18 Canada Goose Overview

The Canada Goose (Branta canadensis) is a large bird that grows to a height of 2 to 3 feet and weighs approximately 10 to 12 pounds. It has a grayish-brown body and wings; black feet, bill and neck; a white underside; and a white patch on each cheek (USDA, 2003). There are 11 subspecies that live in the United States (Virginia Cooperative Extension, 2001b).

Threat to Dam: Canada geese build their nests near water. If they choose to nest on or near an earthen dam, their nesting and feeding activities could cause external erosion.

Canada geese can cause erosion from over-grazing similar to that caused by livestock.

Habitat and Home: Canada geese are found across the United States. Many Canada geese spend their summers in Canada and migrate south to the United States during the winter. Some geese, known as resident Canada geese, spend most of the year in the same general area and fly only far enough to find food or open water (Virginia Cooperative Extension, 2001b). Canada geese nest in areas near open water, such as swamps, marshes, meadows and lakes. Nests are typically made from weeds, twigs, grass, moss, and pine needles (University of Michigan Museum of Zoology, 2002).

Food Habits: Canada geese eat a variety of grasses and aquatic plants. They will also eat crops such as corn, soybeans, and wheat. Young Canada geese require more protein, and will consequently eat insects, small crustaceans, and mollusks (Virginia Cooperative Extension, 2001b).

Behavior: Canada geese are social animals that communicate to each other through a series of calls. They tend to be aggressive birds, particularly the males. They will vigorously defend their territory, nests, and eggs from intruders (University of Michigan Museum of Zoology, 2002).

Field Tip: Canada geese can be easily identified by the white patches on their cheeks. In absence of the birds themselves, Canada geese can be identified by their long, black, cylindrical droppings.

Range of the Canada goose in North America.

Tracks of the Canada goose.

4.2.19 American Alligator Overview

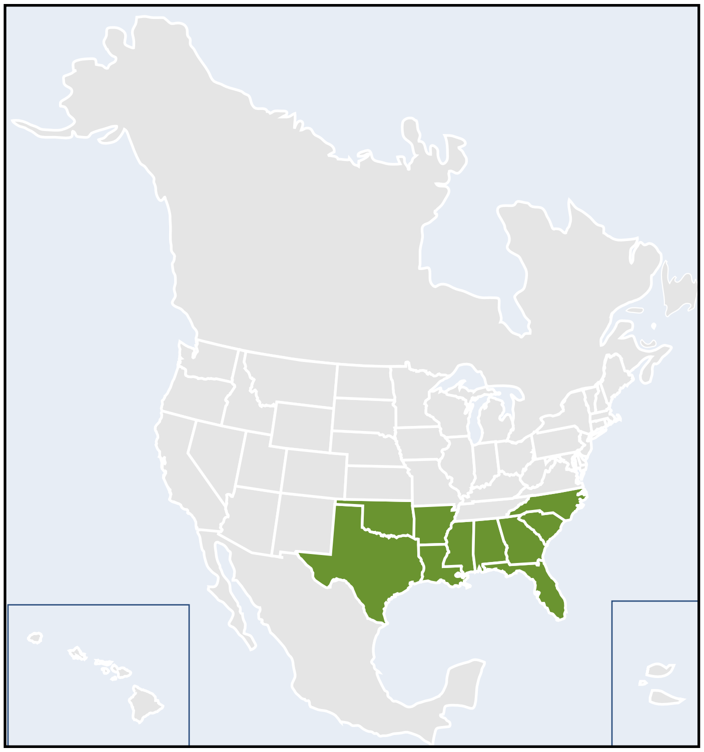
The American Alligator (Alligator mississippiensis) is one of the largest animals in North America. Adult males can grow to a length of 14 feet and weight up to 1,000 pounds. Adult females can grow to a length of 10 feet and weigh up to 250 pounds. They have a rounded snout and black and yellow-white coloration (University of Nebraska, 1994). Alligator hunting is allowed in several states under strict quota or licence guidelines.

Threat to Dam: Alligators sometimes dig burrows or dens for refuge from cold temperatures, drought, and predators. These burrows can cause internal erosion and structural integrity losses in earthen dams (University of Nebraska, 1994).

Habitat and Home: Alligators can be found in almost any type of fresh water, including wetlands, lakes, canals, and streams. They will occasionally inhabit brackish or salt water environments (University of Nebraska, 1994).

Alligators are considered a significant dam safety issue in 2% of the surveyed states.

Food Habits: Alligators will prey upon whatever creatures are most available, including fish, turtles, birds, mammals, and other alligators. Alligators are opportunistic feeders and will eat carrion if it is available and they are sufficiently hungry. If they are near human environments, they may also eat pets and livestock (University of Nebraska, 1994).



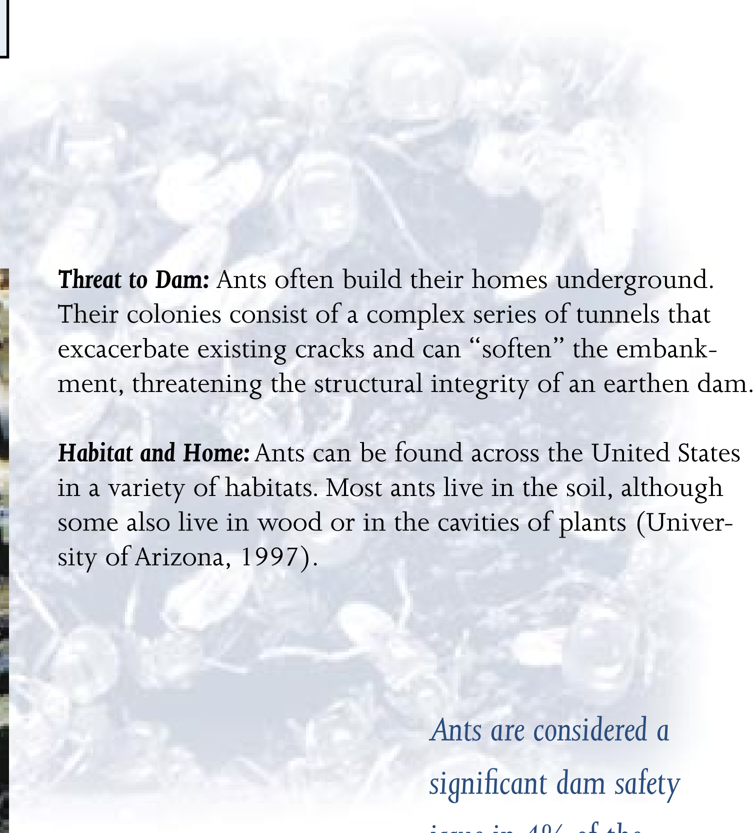
Range of the American alligator in North America.

Behavior: Because they are cold-blooded, alligators are most active when the temperature is warm. When the temperature drops below 70°F, alligators will stop feeding, and when the temperature drops below 55°F, they become dormant. Alligators are not typically aggressive toward humans, but they can and will attack if provoked (University of Nebraska, 1994).

Field Tip: Alligators are large animals, but they blend into their surroundings. It is important to be vigilant and cautious around any water body in the alligator's range.

4.2.20 Ants Overview

Ants (Formicidae spp.) are small insects that live in large colonies. The body of an ant is clearly divided into three sections. Many different species of ants live in the United States. Color and size varies widely across species (University of Florida Cooperative Extension Service, 2002).



Threat to Dam: Ants often build their homes underground. Their colonies consist of a complex series of tunnels that excacerbate existing cracks and can "soften" the embankment, threatening the structural integrity of an earthen dam.

Habitat and Home: Ants can be found across the United States in a variety of habitats. Most ants live in the soil, although some also live in wood or in the cavities of plants (University of Arizona, 1997).

Ants are considered a significant dam safety issue in 4% of the surveyed states.

Range of the ant in North America.

Food Habits: Ants eat a variety of foods, including plants, sugars, seeds, and small insects (University of Florida Cooperative Extension Service, 2002).

Behavior: Ants are social animals. They live in colonies comprised of one or a few queens and many workers. Some ants have a potent sting (University of Arizona, 1997).

Field Tip: Small mounds of soil are often indicative of ant inhabitation.

5.0 Dam Repair And Intrusion Prevention Through Design

Once the inspection is completed according to the guidelines (refer to Chapter 3.0) and considering the biological perspectives presented in Chapter 4.0, the dam specialist will need to take action relative to damages found at the dam. Specifically, the dam owner will need to repair burrow or beaver dam damage, and determine the appropriate level and type of prevention action (e.g., reinforced concrete wall and slab system on upstream slope to prevent muskrat burrows). This Chapter first outlines burrow repair procedures, followed by a discussion of each earthen dam zone (which corresponds to the zones described in Chapter 3.3 of this manual) with regard to the relative priority of prevention action for each zone. Lastly, design options to mitigate and prevent future animal intrusions are presented for each wildlife species. The prevention methods in this chapter relate to modification of the dam or its structures; a discussion of prevention through animal control methods (e.g., trapping) is presented in Chapter 6.0.

The majority of the prevention action design criteria of this Chapter are meant to be incorporated when major features of the dam can be easily altered such as during new dam construction or dam repair construction, when the majority of the dam or a large portion of the dam will be reworked.

The input of a professional engineer is required to ensure proper design and construction of prevention actions.

5.1 Conformity to the Clean Water Act of 1972

The Clean Water Act of 1972 (CWA) is the primary guidance for protecting surface water quality in the United States. The goals of the CWA are to restore and maintain the chemical, physical, and biological integrity of the nation's waters so that they can support "the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water." Towards these goals, the CWA sets water quality standards for waterbodies, which are upheld by antidegradation policies and programs, ambient monitoring, and pollutant load reduction strategies as necessary.

In the dam environment, extensive vegetation removal, burrow excavation and repair, and dam restoration measures could trigger the CWA if dredged or fill materials could be deposited into wetlands or Waters of the United States. As such, all remediation activities must be completed in accordance with the CWA and its provisions, and coordination with the State Dam Safety Official and the State Water Resources Agency is required.

5.2 The Role of Vegetation Management

Proper vegetation management is a cornerstone of effective wildlife intrusion management. In most cases, wildlife will not inhabit an earthen dam that does not provide vegetation for food supply, protective cover, or shelter. If a variety of vegetation exists at the dam, then wildlife will choose to inhabit the earthen dam environment over other areas lacking in vegetation or without a water supply. Ideally, the earthen dam environment will contain appropriate grass species maintained such that dam inspections can be conducted easily without visual obstruction of the embankment and other appurtenant structures. Vegetation such as dense groundcover and thick, woody trees and shrubs not only hinder dam inspections, but can also obscure indicators of potential performance problems such as animal burrows, settlement, depressions, cracks, and similar issues. If vegetation is too thick, animal burrows can go undiscovered and proper animal intrusion mitigation may not occur.

In general, it is advised to limit vegetation at the earthen dam to low-growing native grass that is mowed regularly, and to keep the embankment and spillway inlet and outlets free of vegetation. Vegetated emergency spillways should be maintained in a similar fashion as the dam embankment. Maintained grass will accommodate thorough inspections and limit the number of wildlife species that can easily inhabit the dam. If a dam contains vegetation other than appropriate grasses, then the dam owner should complete mitigation and management as outlined in the FEMA document, *A Technical Manual on the Effects of Tree and Woody Vegetation Root Penetrations on the Safety of Earthen Dams* (FEMA, 2002) and the FEMA brochure, *Dam Owner's Guide to Plant Intrusion of Earthen Dams* (FEMA, 2003).

5.3 Burrow Repair Procedures

Repair actions can be separated into two categories: restoration measures and preventive measures. As the names imply, restoration measures address repairing a deficiency, whereas preventive measures prevent or avert future damage in the area. Specific restoration and preventive measures applicable for various locations in the dam are discussed below.

5.3.1 Restoration Measures

Damage from animal intrusions can occur throughout the dam. The damage can include removal of surface vegetation, rutting, and burrowing. Regardless of the damage location, applicable restoration options depend upon the judged severity of the damage.

Filling Ruts and Near Surface Deformation

Ruts, near surface deformation, and loss of vegetation can be the result of frequent animal crossings, most likely by livestock. Repair of these deficiencies is generally considered not critical. However, if left unattended for a sufficiently long period of time, these deficiencies can result in a progressive loss of vegetation and surface soils due to erosion. In extreme cases, the damage can lead to increasing amounts of erosion in localized areas, jeopardizing performance and requiring significant maintenance. Timely repair of ruts and vegetation loss can save considerable effort and expense later.

The repair methodology for ruts, surface deformation, and vegetation loss includes the following steps:

1. Fill the rut with soil of a similar type to that of the dam embankment. Overfill the rut slightly to account for compaction of the fill material.

2. Compact the soil using hand held or walk behind equipment. In order to achieve reasonable compaction, the fill material should not contain particle sizes greater than 1 inch in diameter. For larger ruts, and ruts created by vehicles, larger diameter material may be acceptable. The compacted surface should be smooth and level with the surrounding ground.

3. Revegetate the area with grass species appropriate for the region (see Chapter 5.2).

Filling Burrows

Methods for repairing or filling an animal burrow are essentially limited to two basic types. The first method considers filling the burrow without excavation while the second method considers excavating the burrow and backfilling the area. Details for each method are discussed below.

Observed burrows without signs of embankment distress (e.g., cracking, slumping) in the area may simply require filling with an impervious material or cementious grout. To fill the entire burrow, a process often referred to as "mud-packing" can be applied. This method consists of placing one or two lengths of metal stove or vent pipe vertically into the burrow. When the pipe is properly sealed, a slurry of 90% earth and 10% concrete, plus an appropriate amount of water to make the slurry flow, is placed in the pipe and allowed to flow into the burrow (Virginia Dam

Safety Program, 2003). The last 6 inches is filled with dirt that will support grass growth.

On the other hand, signs of embankment stress surrounding a burrow may indicate massive soil movement into the burrow. In these cases and at the owner's discretion, complete removal of the burrow is preferred. Shovels or backhoes could be necessary during excavation depending upon the burrow location, size, and depth. Excavation limits will be defined by the burrow size and location as well as the density and type of embankment material. Prior to excavation, dam safety professionals and dam owners should examine potential consequences of soil removal, including slope instability and increased hydraulic gradient. The completed excavation should be thoroughly inspected for adequate removal of the animal burrow. Voids remaining from an animal burrow can develop into potential internal erosion pathways or sinkholes.

Once excavation is complete, the resulting hole must be properly backfilled in a timely manner. Acceptable backfill material should consist of soil types (e.g., sand, clay, etc.) similar to that of the surrounding embankment. If desired, laboratory index testing such as grain size and Atterberg Limits of the backfill and embankment materials may be performed. To achieve adequate compaction of the backfill materials, necessary laboratory testing of backfill materials should include a maximum dry density determination by either the Standard or Modified Proctor test (ASTM D-698 or ASTM D-1557). Backfill material should be compacted to a minimum of 95% of the maximum dry density and within +/- 2% of the optimum moisture content, as determined by ASTM D-698. The completed backfilled surface should be smooth and approximately level with the surrounding ground surface. Backfill should be placed and compacted in lifts of no more than 8 inches thick. A 2 to 4-inch gap can be left between the top of the completed backfill surface and surrounding ground surface to accommodate topsoil.

A local dam safety professional should be notified prior to any excavation activities in an embankment dam.

The final step is to revegetate the disturbed area. Native grass species appropriate for embankment dam slopes should be provided (see Chapter 5.2).

5.3.2 Preventive Measures

For a specific animal intrusion or animal related deficiency, appropriate preventive measures are highly dependent on the affected area's location on the dam. Therefore, common preventive measures are discussed in the context of the Repair Zone in the following section. The use and effectiveness of preventive measures should be assessed by the dam owner in conjunction with a dam safety professional. It may not be cost effective to employ these measures for treatment of animal intrusions alone; however, coincident benefits such as protection against wave erosion and plant intrusion may make the measure more fiscally viable.

5.4 Dam Repair Zones

As discussed in this manual, a variety of animals can damage an embankment dam. The damage can be surfical with minor impact to dam safety or performance, or the damage can directly threaten the integrity of the dam, potentially leading to failure. However, all animal impacts should be considered undesirable and must be repaired. Dam regulators, owners, and engineers should develop an understanding of the potential impact of an animal intrusion to properly evaluate its impact on the safety and performance of the dam (refer to chapter 2.0 for a discussion on animal intrusion impacts).

Prioritization of necessary repairs is critical to maintain a proactive approach to repair and maintenance of a dam. With limited available capital, many dam owners may delay or avoid necessary dam repairs. In addition, routine safety inspections by either regulatory personnel or consulting engineers tend to overwhelm dam owners by listing all observed deficiencies without a clear indication of the relative importance or seriousness of each deficiency. The relative importance and criticality of a specific deficiency depends on the size and nature of the observation (length, width, depth, area, etc.) as well as its location.

Developing a well-defined methodology for evaluating observed deficiencies will permit dam safety professionals to accurately communicate repair prioritization to dam owners. Chapter 3.0 describes an inspection process that considers both engineering and biological perspectives for a dam divided into five distinct zones. These dam zones correspond to specific physical areas of the dam as illustrated on Figure 5-1 (ASDSO, 2001). The intent of the zones is to differentiate and prioritize animal intrusion damages based on their potential impact to dam safety or performance. Depending on the type of animal intrusion or deficiency observed, one or more zones may be considered critical and require near term or immediate repair. However, these critical zones will vary with the dam as well as the dam inspection. Therefore, the zones are not ordered by their importance; rather they are simply ordered from upstream to downstream.

The following sections provide a description of each repair zone, potential damage from animal intrusion, and suggested preventive measures. These descriptions are limited to animal intrusions and their impact to embankment dams. However, other deficiencies such as plant intrusion and erosion can occur within each repair zone. Where appropriate, restoration and preventive measures should consider all observed deficiencies in the area.

5.4.1 Dam Repair Zone 1

Zone 1 begins on the upstream slope at a point approximately 4 vertical feet below the normal pool elevation and extends to the center of the crest. A 4-foot vertical distance was recommended by Marks, et.al. (ASDSO, 2001) to account for average fluctuations in the normal pool and typical underwater animal burrows. The size of Zone 1 can vary significantly from dam to dam because it depends upon the distance between the crest elevation and the normal pool elevation. This distance is often referred to as freeboard.

The relative importance of Zone 1 depends upon the crest width and freeboard. For a dam with a wide crest and large freeboard, animal intrusion within Zone 1 becomes less critical. However, as the crest narrows and freeboard lessens, the importance of repairing deficiencies in Zone 1 increases rapidly.

The most common animal intrusions within Zone 1 are muskrat burrows in which the burrow entrance is underwater as shown on Figure 5-2. However, other intrusions are possible depending upon the specific characteristics of the

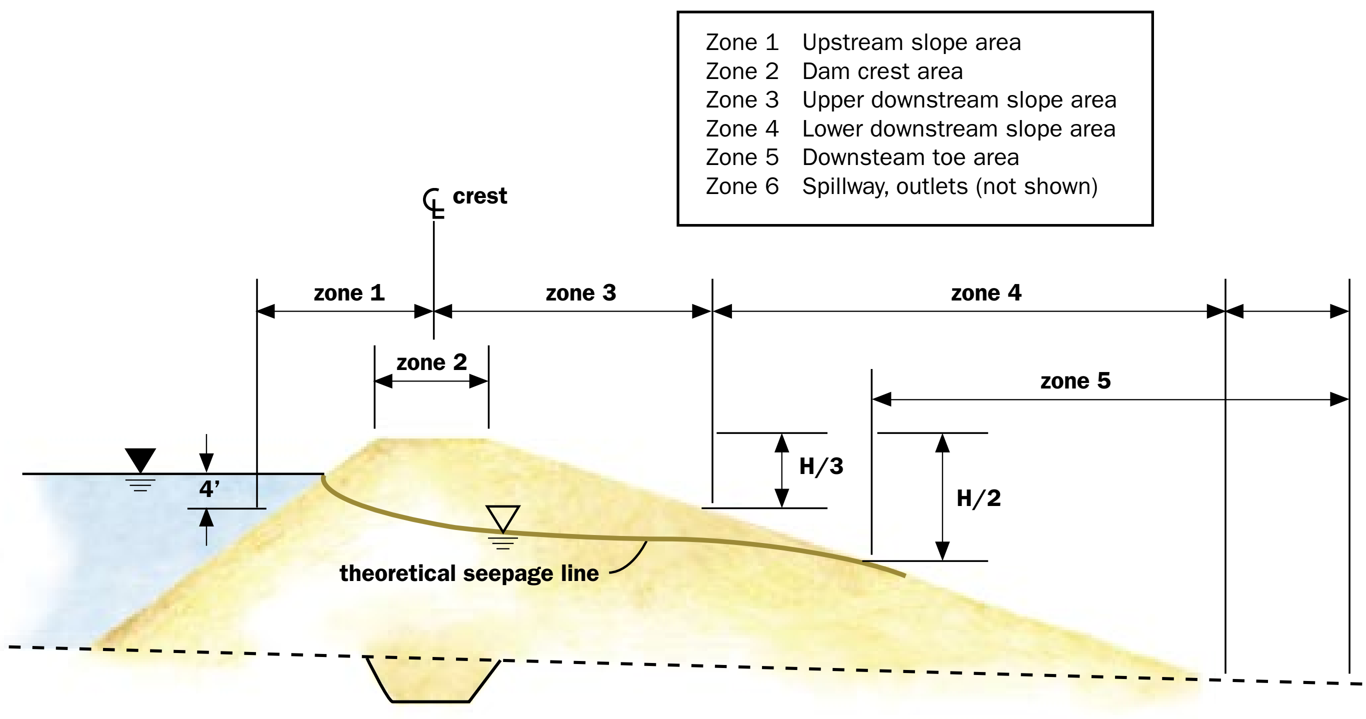


Figure 5-1. Remedial dam repair zones.

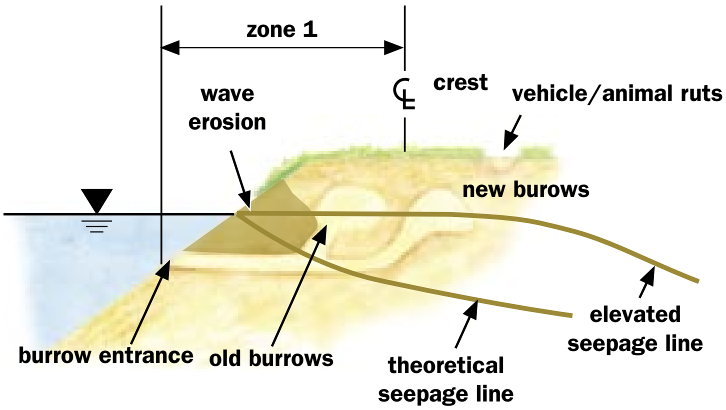


Figure 5-2. Zone 1 Pentration Problems.

dam and reservoir that include geographic location of the dam, proximate vegetation, and prevailing weather patterns. Zone 1 is also susceptible to other forms of deterioration including wave erosion, vehicle access, surface water erosion, and plant intrusion.

To effectively repair animal intrusions in Zone 1, the reservoir pool must be lowered as far below the observed deficiencies as necessary to allow proper access during construction. If the dam owner is unable or unwilling to lower the reservoir pool, then the repair costs will likely increase dramatically to account for necessary water management and diversion.

Preventive measures acceptable for use along the upstream slope generally consist of hardened or structural features. The intent is to provide a physical barrier to the animal, thus making the area much less attractive as a burrow site. These features include riprap, concrete facing, revetment mats, gabions, large gauge wire mesh, and mechanically stabilized earth walls among others. With proper design and installation procedures, each of the methods can be successful. Two of the more common measures are riprap and concrete facing because they are relatively simple to design and provide protection from wave action and plant intrusion as well as animal intrusion.

- A typical cross section of riprap, shown on Figure 5-3 (Ohio DNR, 1999) should consist of a layer of rock riprap overlying bedding material and filter material or a geotextile separator. Limits of the protection should extend at least 4 feet below the normal pool elevation and several feet above depending on estimated wave heights and average reservoir fluctuation. Rock size and layer thickness will vary significantly from dam to dam depending on the reservoir size, prevailing winds and other physical characteristics of the area. Therefore, material (e.g. riprap, bedding and filter) sizes and layer thickness, must be based on the anticipated wave action, ice thickness, and compatibility with neighboring materials. A number of guidelines including Technical Release No. 69 developed by USDA, Natural Resources Conservation Service can assist dam safety professionals in detailed design for riprap slope protection.
- A typical cross section of concrete facing as shown on Figure 5-4 (Ohio DNR, 1999) will resemble riprap in that the concrete will overlie a filter material. As with riprap, the concrete facing limits should extend at least

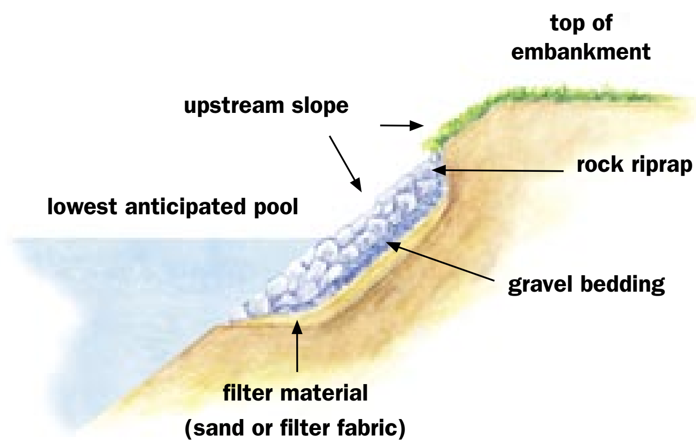


Figure 5-3. Riprap Repair in Zone 1.

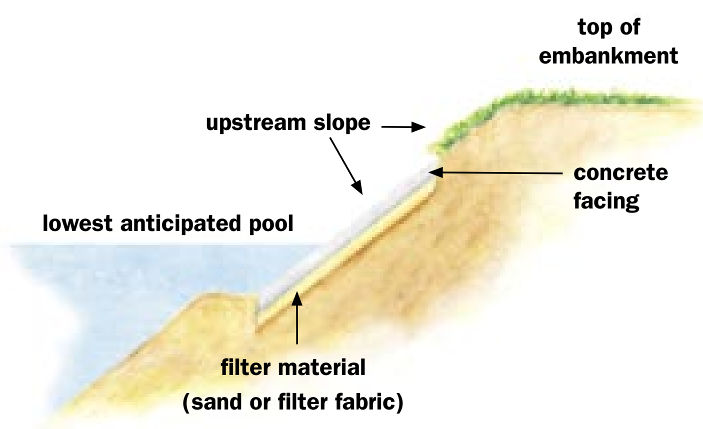


Figure 5-4. Concrete Facing in Zone 1.

4 feet below the normal pool elevation and several feet above, depending on estimated wave heights and average reservoir fluctuation. Concrete thickness, compressive strength, and reinforcing depend on wave action, freeze/thaw cycles and other factors.

Regardless of the measure selected, proper implementation requires specific design recommendations from a qualified dam safety professional.

5.4.2 Dam Repair Zone 2

Repair Zone 2 corresponds to the limits of the dam crest and, therefore, overlaps with Zone 1 by one-half of the crest width. Overlapping a portion of Zone 1 with Zone 2 emphasizes the importance and critical nature of both zones. This overlap essentially suggests that both zones be inspected twice during a dam safety inspection.

As with Zone 1, the relative importance of Zone 2 depends upon the crest width and freeboard. For a dam with a wide crest and large freeboard, animal intrusion within Zone 2 becomes less critical. However, as the crest narrows and freeboard lessens, the importance of repairing deficiencies increases rapidly. These intrusions may include terrestrial animal burrows such those made by groundhog, but most typically include ruts and other minor deformations. Zone 2 is also susceptible to other forms of deterioration including vehicle access, surface water erosion, and plant intrusion.

Restoration of animal penetrations within Zone 2 should follow the guidelines presented in Chapter 5.3. Any excavation activities within a dam embankment should be coordinated with a dam safety professional.

Applicable preventive measures for Zone 2 include hardening the crest surface with stone, concrete, or asphalt. These measures tend to prevent rutting from animal and vehicular traffic. Design of these measures depends upon the specific characteristics of the dam and expected loading conditions.

5.4.3 Dam Repair Zone 3

Repair Zone 3 begins at the crest centerline and extends to a point on the downstream slope equivalent to one-third the structural height of the dam below the dam crest elevation. As with Zone 2, Zone 3 overlaps Zone 2 by one-half of the crest width to emphasize the importance of the dam crest area. However, the remaining portion of Zone 3 is typically considered the least critical dam repair zone relative to dam safety issues (ASDSO, 2001). The phreatic surface and zone of saturation within the embankment are generally below the depths of average animal burrows and should not interfere with restoration activities.

Zone 3 is the most attractive area for burrows of terrestrial animal, including groundhog, fox, and coyote. Similar to all other zones, Zone 3 is also susceptible to other forms of deterioration including vehicle access, surface water erosion, and plant intrusion.

Restoration of animal penetrations within Zone 3 should follow the guidelines presented in Chapter 5.3.1 and as shown on Figure 5-5. Any excavation activities within a dam embankment should be coordinated with a dam safety professional.

Applicable preventive measures for Zone 3 (beyond the limits of Zone 2) are limited. Use of hardening materials such as stone, riprap, or concrete is generally discouraged by dam safety professionals because they obscure the surface and prevent detailed inspection. Installation of wire mesh or fencing (e.g., chain link fencing) directly on the ground surface can effectively deter to burrowing animals. With properly sized openings, the wire mesh deters animal intruders and accommodates inspection of the area. However, these materials can represent an obstacle to routine maintenance activities such as mowing and be viewed as a tripping hazard.

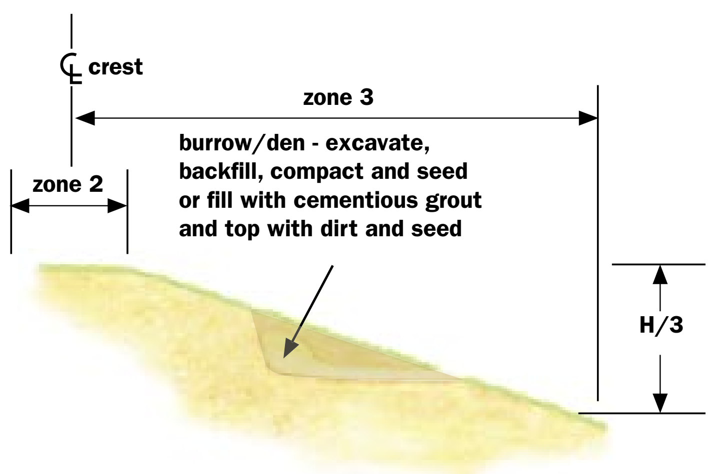


Figure 5-5. Zone 2 and 3 Repair Procedures.

5.4.4 Dam Repair Zone 4

Repair Zone 4 extends from the point on the downstream slope that is one-third the dams' structural height below the crest to the toe of the downstream slope. Zone 4 is one of the two most critical dam repair zones relative to dam safety issues because of the proximity of the phreatic surface and zone of saturation to the embankment slope.

Animal and plant intrusions within this repair zone should be of major concern to dam owners and dam safety professionals. Any animal intrusion or dam penetration should be thoroughly evaluated for potential impact to dam safety and for the required repair.

Restoration of animal burrows within Zone 4 should follow procedures presented in Chapter 5.3. However, due to the proximity of the phreatic surface to the animal burrow, the increased potential of soil migration and, therefore controlling water in the restored burrow must be considered. As shown in Figure 5-6, the use of filter materials within the backfilled burrow can control internal erosion, and with small diameter plastic piping, can manage the flow of water in the area.

Similar to Zone 3, use of hardening materials such as stone, riprap, or concrete is generally discouraged by dam safety professionals because they obscure the surface and prevent detailed inspection. The use of wire mesh or fencing as discussed for Zone 3 is also applicable to Zone 4. It is essential that restoration and preventive measures in Zone 4 undergo review from a dam safety professional prior to implementation.

5.4.5 Dam Repair Zone 5

Repair Zone 5 begins at the mid-height of the downstream slope and extends to a distance of one-half of the dam's structural height horizontally beyond the downstream toe. Zone 5 overlaps a large portion of Zone 4 to emphasize the most critical portions of both zones and heighten scrutiny during inspection. Zone 5 is typically considered the most critical zone relative to dam safety issues (ASDSO, 2001) because the interception of the phreatic surface and downstream slope is typically located in this zone for homogeneous dams.

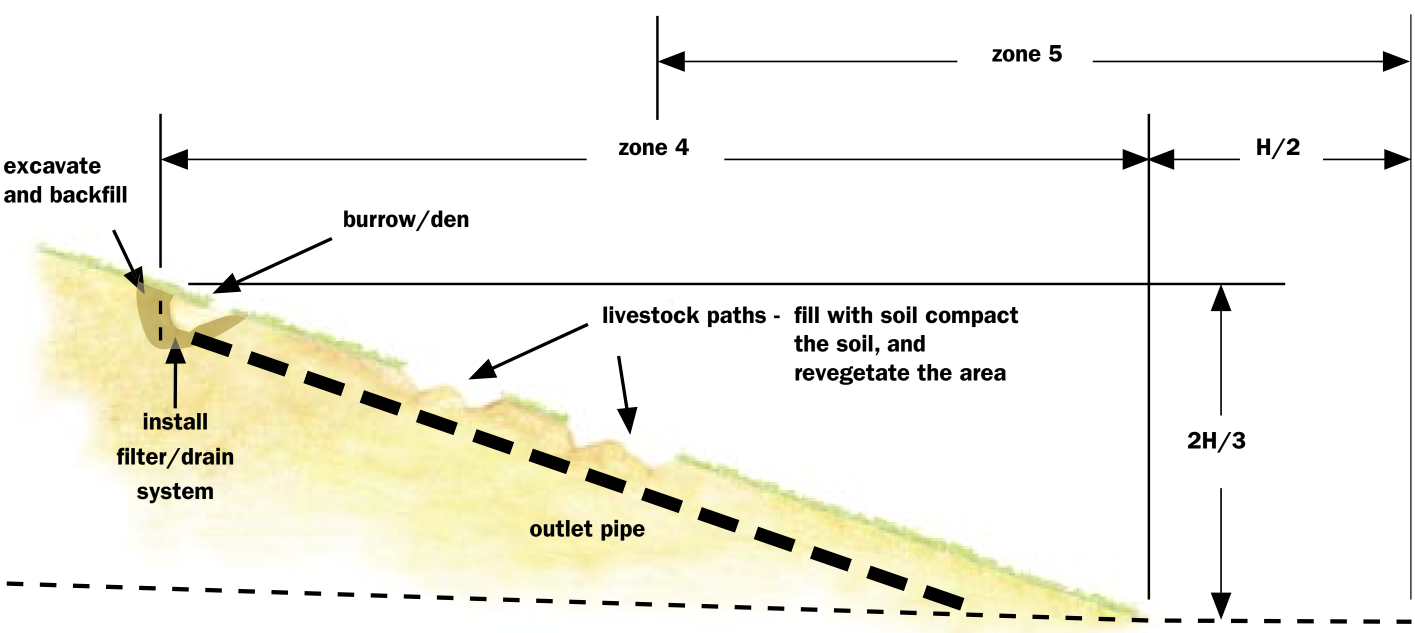


Figure 5-6. Zone 4 and 5 Repair Procedures.

Animal and plant intrusions in this zone often develop into serious conditions involving seepage and piping that are progressive and can lead to dam failure if left untreated. The installation of filter and drain systems to control soil migration and manage seepage must be considered in Zone 5. Similar to Zone 3 and 4, the use of wire mesh of fencing to deter animal intruders can also be considered in Zone 5. It is essential that restoration and preventive measures in Zone 5 undergo review from a dam safety professional prior to implementation.

5.5 Professional Dam Safety Review

Construction or repair activities on an embankment dam should be reviewed by a dam safety professional prior to initiation. Due to the complexity of interaction among animal penetrations, the phreatic surface, slope stability, and other deficiencies, the impact of excavation activities on a dam can be unpredictable without thorough review by a qualified professional. This review should include the following elements at a minimum:

- Evaluation of the existing dam relative to the position of the phreatic surface and slope stability through review of pre-existing inspection reports, design drawings, design memoranda, and owner observations.
- Assessment of the impact of excavation given the phreatic surface position and physical characteristics of embankment materials (material type, density, plasticity, etc.).
- Evaluation of the restoration and preventive scheme proposed.

5.6 Sequenced Repair Program

Currently, dam safety inspections provide a comprehensive list of deficiencies observed at the time of the inspection. The list is generally separated into physical areas of the dam including the upstream slope, crest, downstream slope, emergency spillway, and principal spillway. However, in most cases, the list is not prioritized for the dam owner. Consequently, the dam owner is left with a long list of deficiencies with little guidance on immediate, near-term, and long-term repair items.

Considering that most dam owners do not have the financial means to address all deficiencies quickly, a prioritization methodology should be established for dam repair. The following sequence is one that provides the owner, regulator, and dam safety engineer with a reasonable opportunity to effectively evaluate the condition of an earthen dam (ASDSO, 2001). It must be noted that the following sequence is intended for general guidance only. Specific dam inspections may substantially deviate from the following sequence based on the needs and requirements of the individual dam.

- **Year 1.** (from date of last inspection) Repair animal penetrations that exhibit seepage, soil migration, or have caused slope instability in Zones 1, 4, or 5. Preventive measures should be installed where appropriate.
- **Year 2.** Repair penetrations in Zones 2 and 3. If deemed necessary, initiate investigation, analysis, and preliminary design of major repair activities.
- **Year 3.** Complete design and begin construction of major repair activities.
- **Year 4.** Complete construction of major repair activities and establish an operation and maintenance program that will manage animal intrusions and penetrations on a frequent and regular basis.

If dam failure is judged imminent or if dam safety or operation has greatly diminished, the above sequence may not be applicable. In these cases, a dam safety professional must be advised of the situation to develop a revised schedule.

5.7 Mitigation Through Design

5.7.1 Muskrat

Some of these design criteria are referred to as "overbuilding" however, they are generally effective at preventing serious muskrat burrow damages. The design measures are adapted from the following references: University of Nebraska, 1994; University of Missouri Extension, 1999; ASDSO, 2001; Connecticut DEP, 1999; USDA, 1991; and South Carolina DNR, 2003.

- Construct the upstream slope of the dam to a 3H to 1V slope. Muskrats favor steep slopes so gentle slopes will be less attractive (Figure 5-7).
- Construct the downstream slope of the dam at a 2H to 1V slope with a crest width of not less than 8 feet, preferably 10 to 12 feet.

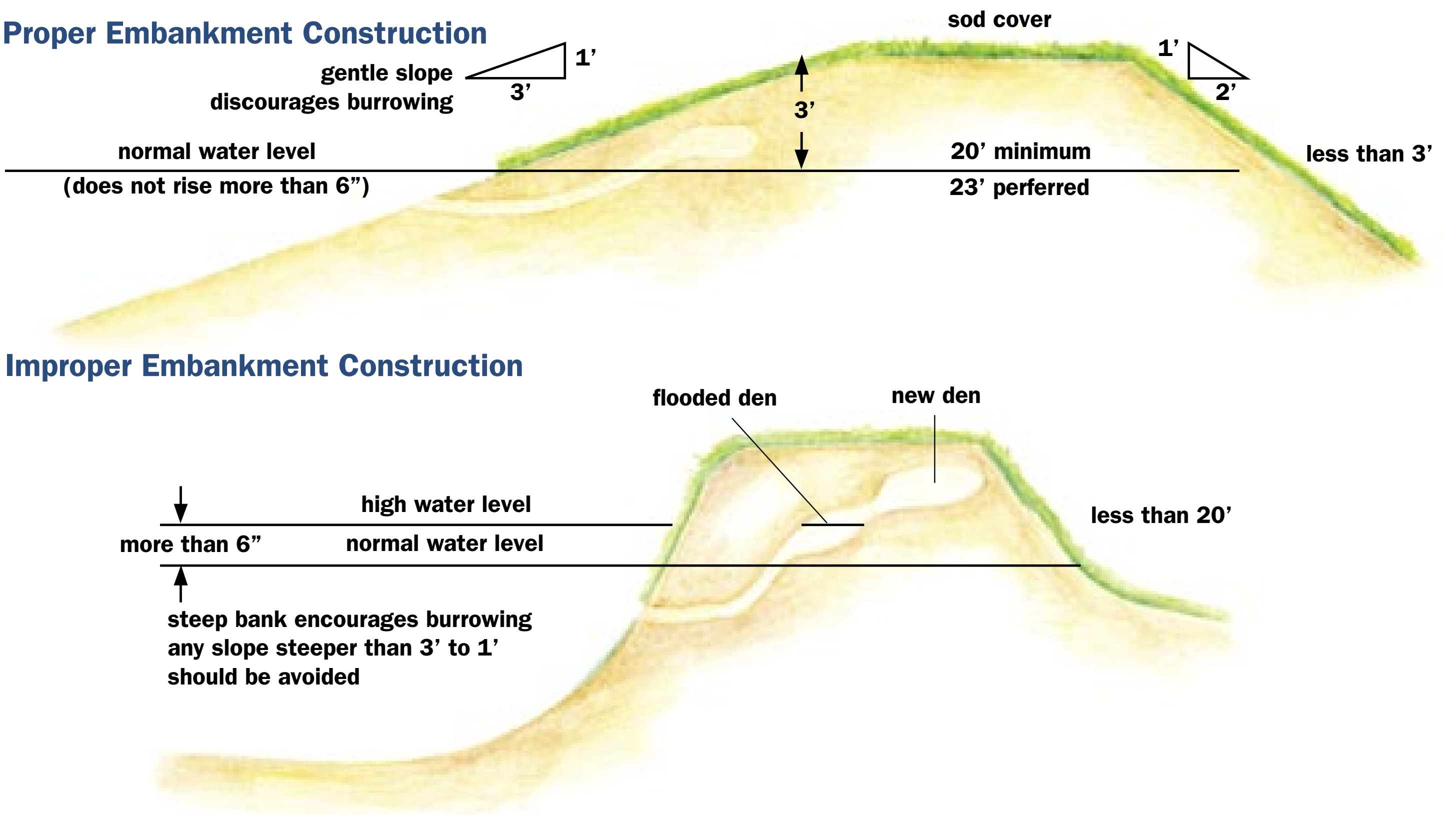


Figure 5-7. Proper dam construction can reduce muskrat damage.

- The normal water level in the pond should be at least 3 feet below the top of the dam and the spillway should be wide enough that relatively frequent storms (less than the 10 year storm event) will not increase the level of the water for any length of time.

- Design for a minimum width of 20 feet at normal water level.

- Bind soil adequately by sodding well.

- Protect the crest from muskrat by applying compacted dense-graded aggregate base course 4 to 6 inches thick.

- Construct a 10-foot-wide shelf projecting from the face of the dam into the reservoir at the water line. This shelf will act as a muskrat barrier and also reduce wave action erosion.

- Place stone rip-rap underlain by fine filter stone and geotextile (high strength, non-woven) extending from 3 to 4 feet below the water line to 1 foot above the water line. Riprap size and thickness will depend upon specific reservoir characteristics. The riprap will prevent muskrat from burrowing into the dam.

- Use an appropriate gabion wall system and/or enlarged reinforced concrete outlet works structures to act as exclusion systems at the toe of the downstream slope.

- Embed 1 to 2-inch welded wire or chain link fencing into the dam upstream face. Mesh wire should extend from 3 to 4 feet below the water line to 1 foot above the water line. Lay the wire flat against the banks and fasten it down every few feet to secure the wire. It is likely that portions of the mesh below the water surface will corrode over time and require replacement.

- Using a narrow trenching machine, cut a vertical trench extending the full length of the embankment in the centerline of the earth fill. The trench should extend from 3 to 4 feet below the water line to 1 foot above the water line. Fill the trench with concrete to create a core that will prevent muskrat from digging through the embankment.

The South Carolina Dam Safety Office indicates that using siphons and other "non-trickle" principal spillway systems may be effective against beaver, but their success is not documented.

- Design water control structures with a concrete apron to prevent muskrat burrows from damaging these facilities.

Several of the above design components indicate placement of the barrier 3 to 4 feet below the water line of the normal pool. It should be noted that if the barriers are not placed at least 3 feet (and preferably 4 feet) below the water line, then the muskrat will burrow underneath the barrier and penetrate the embankment; failure of the slope protection system and embankment damages will result.

5.7.2 Beaver

Structures or techniques to prevent beaver damage can often be included in initial engineering plans or added during dam upgrades and repairs. The following techniques have been adapted from the following references: University of Nebraska, 1994; North Carolina State University, 1994; Wilson, 2001; New York State DEC, 2002; Porter, 2003; Barnes, 1991; Virginia Cooperative Extension, 2000; and FEMA, 2000.

- Gently slope the embankment (3H to 1V or flatter) to discourage burrowing and minimize the probability of beaver dam construction.

- Install spillway risers so that they open upstream instead of toward the dam.

- Place riser structures far from the face of the dam in the deepest water possible.

- Protect large risers from clogging by installing mesh bars (at least 5 inches square) or hog pen panel (4 x 4 inches). This will prevent beaver from entering the trash rack.

- Protect intakes with a deep water cage or fence to prevent plugging.

- Replace the standard manhole cover on top of the riser tower with a "beehive" grate. This cast iron dome allows drainage during high water events, even if the lower orifices are blocked.

- Install a single strand, high-tensile electric wire across active beaver paths or around the shoreline just above the slope where beavers would exit the water. The electric wire should be staked about 3 to 4 inches above the soil surface and can be powered by a direct 110-volt charger or a rechargeable battery pack. After repeated shocks, the beaver will usually relocate to another area. Public safety issues and concerns must be addressed when considering this option.

- Install fencing around outlets to prevent plugging. Secure the fence to the reservoir bottom with metal posts. Fencing should be about 5 feet high, made of heavy-gauge woven wire with no larger than 6-inch openings. It should extend 10 to 20 feet out from the outlet. Before installing the fence, debris should be removed from the outlet (Figure 5-8).

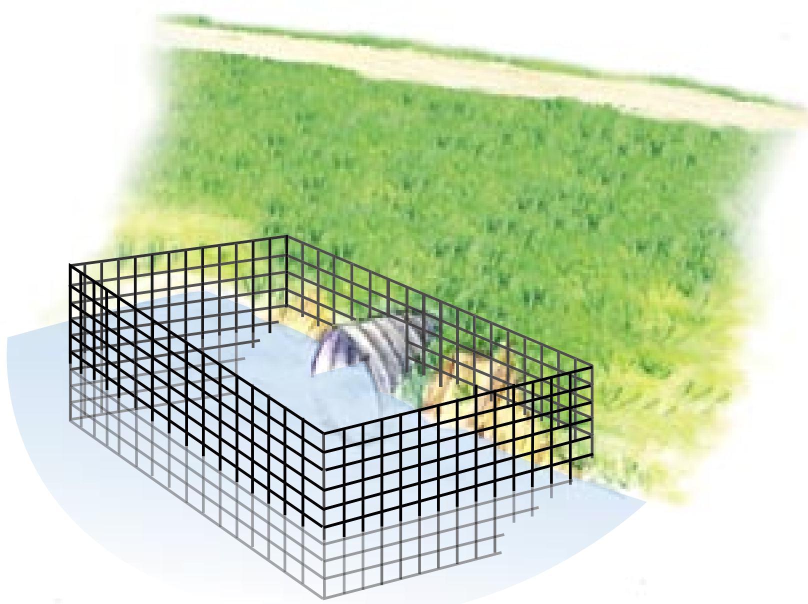


Figure 5-8. Install fencing around culverts and outlets to prevent beavers from blocking flow.

Avoid These Water Level Control Devices at Dams

Because these devices require partial obstruction of spillways or outlet pipes, their use at a dam should be strictly prohibited. Obstruction of spillways or outlets can cause reservoir levels to rise resulting in overtopping of the dam, erosion of earthen spillways and other detrimental impacts.

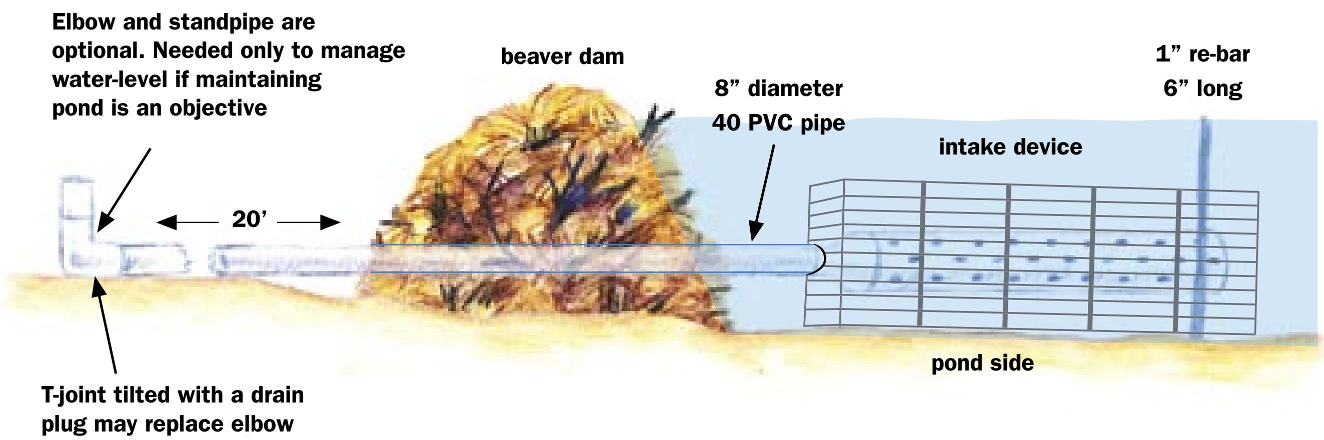


Figure 5-9. The Clemson Beaver Pond Leveler is a passive but effective means to control water levels through a beaver dam.

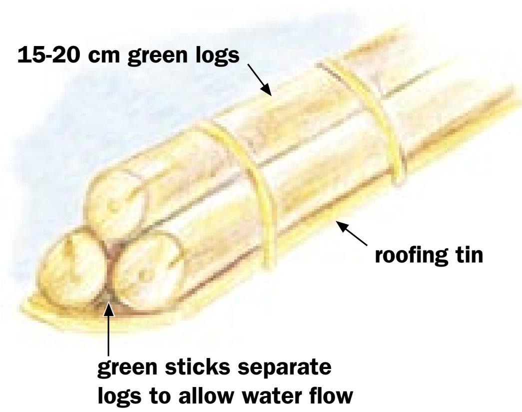


Figure 5-10. A 3-log drain manipulates water levels through a beaver dam.

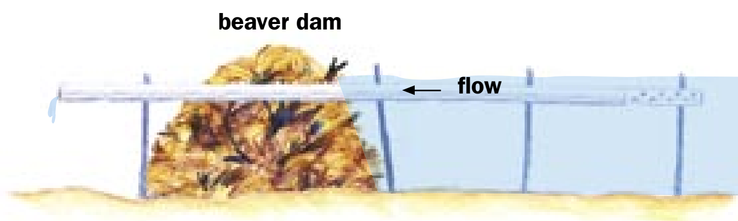


Figure 5-11. PVC Beaver Drain Pipe

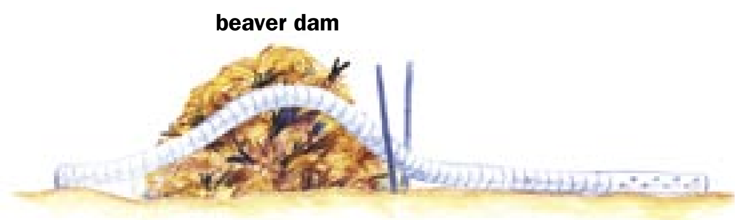


Figure 5-12. Massachusetts Beaver Pond Leveler

- Install a layer of riprap on the upstream side of the embankment to prevent burrowing. The riprap should extend from 4 feet below to 2 feet above normal water levels.

5.7.3 Mountain Beaver

It may be possible to exclude mountain beavers from a dam by installing a rabbit-proof fence (chain-link, chicken wire, etc.) around the embankment. The bottom of the fence must be tight against the ground or, for better protection, buried about 1 to 2 feet (Pehling, 2003).

5.7.4 Groundhog

It is possible to discourage groundhogs from burrowing in an earthen dam by armoring the structure with rock or other hard materials (Michigan State University Extension, 1998).

It is also possible to exclude groundhogs from an earthen dam by installing a fence around the area of concern. Groundhogs are good climbers so the fence should be at least 3 feet high and made of heavy poultry wire or 2-inch mesh woven wire. To prevent burrowing underneath the fence, it should be buried 10 to 12 inches into the ground or bent into an L-shaped angle (pointing away from the excluded area) buried 1 to 2 inches into the ground. For added protection, an electric wire placed 4 to 5 inches off the ground and 4 to 5 inches away from the fence may be installed (University of Nebraska, 1994). Public safety issues and concerns must be addressed when considering this option.

5.7.5 Pocket Gopher

Fencing is of limited use for protecting earthen dams from pocket gophers; the method is expensive and generally not practical because pocket gophers burrow so deeply underground. However, if fencing is used to exclude pocket gophers from the dam, it should be buried at least 20 inches into the ground and extend 6 to 8 inches above the ground (USDA, 1991).

5.7.6 North American Badger

Fencing may be used to exclude badgers from an earthen dam. The fence should be made of mesh wire and it should be buried to a depth of 12 to 18 inches to prevent badgers from burrowing underneath. This control method may not be practical for protecting large areas because installation can be costly and time consuming (University of Nebraska, 1994).

5.7.7 Nutria

There are several design measures that can be implemented to reduce nutria damage.

- Install fencing around the dam embankment. Fences should be about 4 feet high with at least 6 inches of fencing buried underground.

- Armor the embankment with riprap to discourage burrowing.

- Contour embankment slopes to an angle less than 45° to discourage burrowing.

5.7.8 Prairie Dog

The use of fencing to exclude prairie dogs from a dam is a potential management tool, although it is rarely practical because prairie dogs burrow so deeply underground. If fencing is chosen as a control method, a tight-mesh, heavy-gauge, galvanized wire fence should be used, with 2 feet buried in the ground and 3 feet remaining above ground (University of Nebraska, 1994).

Visual barriers may also discourage prairie dogs from inhabiting an area. Prairie dogs prefer areas of low vegetation to provide a clear view of their surroundings and to improve their ability to detect predators. Objects such as fences or hay bales that are strategically placed to block prairie dog views may reduce suitability of the habitat. High construction and maintenance costs generally reduce the viability of this option (University of Nebraska, 1994).

5.7.9 Ground Squirrel

Fencing is not usually a practical method of control for ground squirrels because they are able to climb over or burrow under most exclusion structures. Routine weed control and vegetative management may limit some damage, but the effectiveness of this method is usually limited as well (USDA, 1991).

5.7.10 Armadillo

It is possible to exclude armadillos from an earthen dam by installing a fence or barrier around areas of concern. Armadillos can both climb and burrow so the fence should be slanted outward at a 40° angle with a portion buried underground sufficient to maintain the fence's pitch.

5.7.11 Livestock

Fencing is a highly effective method of protecting earthen dams from domestic livestock and is moderately effective with free-ranging or wild grazing animals (USDA, 1991). Heavy wire fences, wooden post fences, or electric fences may be used (University of Nebraska, 1994).

5.7.12 Crayfish

No design techniques are effective at discouraging crayfish inhabitation.

5.7.13 Coyote

Fencing can be used to exclude coyotes from a dam. Both wire and electric fences will work, and a combination of the two will probably be most effective. Net wire fences should be about 5 feet high with barbed wire at ground level or a buried wire apron. Horizontal spacing of the mesh should be less than 6 inches and vertical spacing should be less than 4 inches. Electric fences usually consist of strands of smooth, high-tensile wire stretched to a tension of 200 to 300 pounds. Studies have shown that 13 strands of charged wire effectively protected pastures from coyote predation (University of Nebraska, 1994).

Studies have shown that 13 strands of charged wire effectively protected pastures from coyote predation.

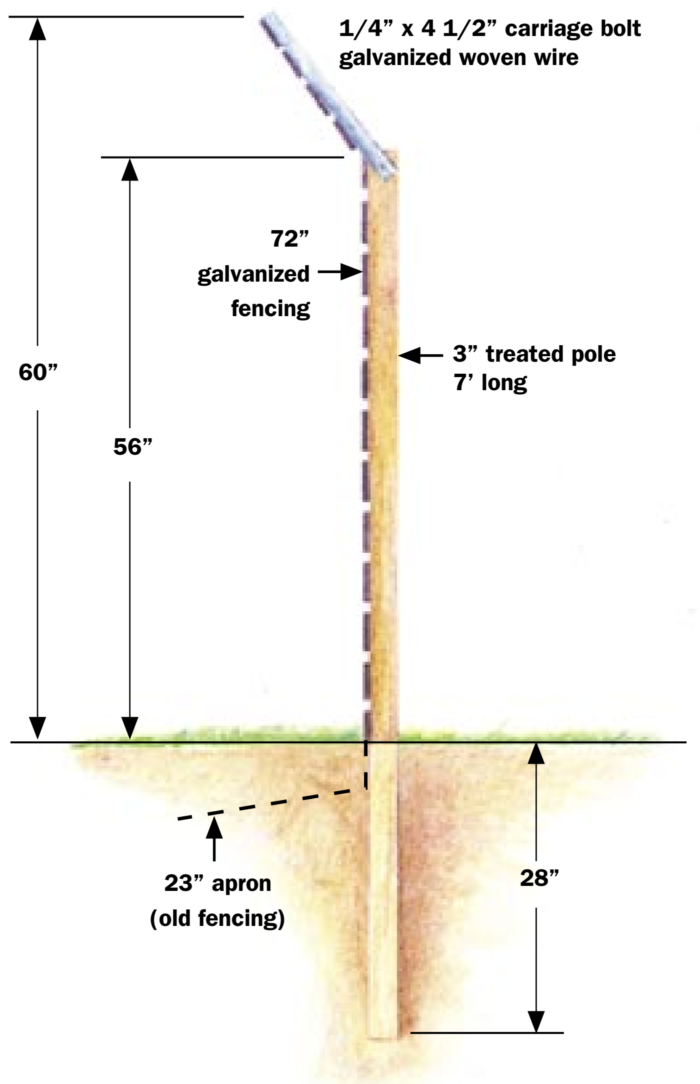


Figure 5-13. Installation of a net fence with wire overhang and buried apron is an effective coyote exclusion method.

5.7.14 Mole and Vole

Fencing may be useful for mole control in small dams. The fence should be made of rolled sheet metal or hardware cloth, with at least 12 inches buried underground and 12 inches extending aboveground. It is also possible to discourage moles from burrowing in an earthen dam by packing the soil with a roller to reduce soil moisture. This will reduce the habitat's attractiveness to moles (University of Nebraska, 1994).

Fencing of large-scale areas is generally not a cost-effective method of vole control (University of Nebraska, 1994).

5.7.15 River Otter

Fencing may be used to exclude river otters from an earthen dam. The fence should be constructed of mesh wire (3 x 3-inch or smaller) or hog-wire. Dam owners should regularly check the fence to ensure that it has not been spread apart or raised to allow otters to enter (University of Nebraska, 1994).

5.7.16 Gopher Tortoise

Fencing the dam embankment may be practical for protecting small areas from gopher tortoise damage (University of Nebraska, 1994).

5.7.17 Red and Gray Fox

Fencing can be used to exclude foxes from an area of concern. Both wire and electric fences will work, and a combination of the two will probably be most effective. Net wire fences should be constructed so that all openings are less than 3 inches. The bottom should be buried 1 to 2 feet into the ground with at least 1 foot above ground. For an effective electric fence, there should be at least three charged wires spaced 6 inches, 12 inches, and 18 inches above the ground (University of Nebraska, 1994).

5.7.18 Canada Goose

It is often possible to discourage Canada goose inhabitation by installing fencing, rock barriers, or vegetative barriers around shorelines. Fencing can be constructed out of a variety of materials including mylar tape, metal mesh, plastic or synthetic mesh, electric wires, or wood. Fences should be at least 25 inches tall and should not contain openings greater than 3 inches (Virginia Cooperative Extension, 2001b).

5.7.19 American Alligator

Fencing may be used to exclude alligators from earthen dams. The fence should be at least 5 feet high with the top edge angled outward (University of Nebraska, 1994).

5.7.20 Ants

There are no exclusion methods or design measures effective against ant inhabitation

5.8 Monitoring

Once a dam specialist identifies the burrow and the species creating or occupying it, the burrow(s) would be filled and a prevention technique implemented as appropriate. The next step to maintaining safe dam operation is to monitor the effectiveness of the remedial action (e.g., has the riprap effectively deterred muskrat activity?). In many cases, regular dam inspections and swift burrow mitigation (and preventive actions when needed) will adequately preserve safe dam operations. However, it is possible for a dam to become overrun by nuisance animals, or for several species to cumulatively compromise safe dam operations. In these cases, repair actions are only partial solutions. Monitoring can help the dam owner determine whether additional mitigation is necessary.

In general, it is recommended that the dam owner inspect the dam once every 3 months after first finding and repairing animal damage. The frequency is aimed at confirming the animal has not returned to the dam once the burrow is removed. Once burrows are identified, the owner should consider implementing a preventive action if a burrow occurred in one of the critical dam zones (see Chapter 5.4 for a discussion on animal burrows in critical dam zones). Understanding the potential fiscal limitations of dam owners, the most realistic approach is to use the fewest actions needed to ensure dam safety. As a guideline, if the dam owner finds new animal burrows in the dam on two consecutive inspections following repair and preventive actions, then implementing a wildlife control strategy is probably necessary to maintain safe dam operations (see Chapter 6.0 for a discussion on wildlife control).

6.0 Mitigating Damaging Wildlife

This chapter of the manual details methods for managing wildlife populations. General wildlife management information is provided first, followed by specific management information for the 23 species considered in this manual. The application of this data in the dam environment can be beneficial and at times necessary to protect human populations from the disastrous effects of dam failure. However, applied indiscriminately, these methods can adversely affect the dam environment, protected wildlife species, and even human populations. For this reason, nuisance wildlife management practices should be implemented only with coordination and input from state and federal wildlife agencies and the county agent responsible for toxicant and fumigant registration and application (Appendix A contains state wildlife contacts).

6.1 Compliance with State and Federal Regulations

6.1.1 Conformity to Federal Regulations

As the vast majority of surveyed states indicate, the dam owner is responsible for the identification and mitigation of nuisance wildlife at dams. Although the dam owner is empowered by the state dam safety official to manage a dam toward safe operation, the dam owner must abide by applicable federal and state regulations when implementing nuisance wildlife management measures. The Endangered Species Act of 1973 (ESA), the Migratory Bird Treaty Act of 1918 (MBTA), and the Federal Insecticide, Fungicide, and Rodenticide Act of 1996 (FIFRA) are three federal laws that must be complied with during application of wildlife management methods. The ESA protects species of plants and animals that are in danger of extinction. Under the ESA, it is illegal for anyone to "take" a species listed as threatened or endangered.

The ESA defines "take" as, "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or attempt to engage in any such conduct" (USFWS, 2002a). The MBTA was established to conserve migratory bird species in the United States and prohibits the hunting, trapping, possession, and transfer of listed species except under the terms of a valid permit or during authorized hunting seasons (USFWS, 2002b).

Species that are discussed in this manual and protected under the ESA and the MBTA include:

- Gopher Tortoise (*Gopherus polyphemus*). This species is listed as Threatened under the ESA throughout its range of Mississippi, Louisiana, and portions of Alabama, and is protected by state laws in Alabama, Georgia, Florida, and South Carolina.

- The American Alligator (*Alligator mississippiensis*). This species is listed as "Threatened by Similarity of Appearance to a Threatened Taxon" under the ESA throughout its range of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, and Texas. This designation means that the American Alligator is protected under the ESA because of its similarity in appearance to the American Crocodile (*Crocodylus acutus*). The American Crocodile is classified as Endangered under the ESA. The USFWS determined that in order to adequately protect the American Crocodile, which is often mistaken for the American Alligator, the USFWS must also protect the American Alligator. Therefore, though populations of the American Alligator are healthy throughout its range, it is afforded full protection under the ESA.

- Point Arena Mountain Beaver (*Aplodontia rufa nigra*). This subspecies is listed as Endangered throughout its range of California.

- Utah Prairie Dog (*Cynomys parvidens*). This species is listed as Threatened throughout its range of Utah.

- Northern Idaho Ground Squirrel (*Spermophilus brunneus brunneus*). This subspecies is listed as Threatened throughout its range of Idaho.

- Canada Goose (*Branta canadensis*). This species is protected under the MBTA throughout its range of the United States.

If dam owners suspect that one of these species is damaging the earthen dam, then the dam owner must contact the USFWS and the state wildlife agency to discuss management options. While it is often possible to relocate these animals with permits and guidance from the USFWS and the state wildlife agency, the permitting agency must be consulted prior to taking any action. It should be noted that the list of protected species can and does change, and regular contact with an agency is required to ensure that no protected species are adversely affected.

While difficult to predict each potential circumstance, there may be cases when management of a species not protected by the ESA or MBTA may result in the illegal taking of a protected species that is associated with the targeted nuisance species. For example, the endangered black-footed ferret (*Mustela nigripes*) depends on the burrows of prairie dog colonies for survival. Mitigation against the prairie dog may impact the ferret. Similarly, the eastern indigo snake (*Drymarchon corais couperi*) is afforded refuge by gopher tortoise burrows; thus, managing a dam for the tortoise could have secondary effects on the indigo snake. As some species show interdependencies on others, it is recommended that coordination with state and federal wildlife agencies be conducted before management of any species, protected or not, occurs.

Last, FIFRA divides pesticides, including toxicants and fumigants, into two categories: General Use Pesticides and Restricted Use Pesticides. General Use Pesticides will not ordinarily cause unreasonable adverse effects on the user or the environment when used as directed and as such, they are commercially available to the public. Restricted Use Pesticides, however, could cause adverse effects to the user or the environment even when used correctly. Restricted Use Pesticides can only be purchased by a certified pesticide applicator and applied by or under the supervision of a certified pesticide applicator, in accordance with FIFRA. Appropriate disposal of pesticide containers is also required.

6.1.2 Conformity to State Regulations

Certain wildlife species are protected by the state even though they are not listed as Federally threatened or endangered; each state determines its own regulations with regard to protected species. Furthermore, hunting and trapping regulations in regard to furbearer, game, and nongame species vary from state to state. For these reasons, it is recommended that a dam owner contact the appropriate state wildlife agency for information about mitigation of wildlife species, and hunting and trapping seasons, licenses, and permits before attempting to remove an animal from the dam environment or before any wildlife management actions are taken. As with federal laws, the list of protected species can change from year to year and regular contact with an agency is required to ensure that no protected species are adversely affected.

Finally, legal use of specific toxicants and fumigants varies from state to state; one state may allow a toxicant that is banned in another. As such, it is recommended that coordination with the state wildlife agency or county agent be conducted to determine which substances are allowed for use in each state. If toxicants or fumigants are selected as the management option, it is recommended that:

- The substance is used according to direction and precaution;
- The substance is stored securely in original containers away from children, animals, food, and feed;
- The substance is applied so as not to endanger humans, livestock, crops, beneficial wildlife, or water supply, or leave illegal residues;
- Excess substance is not dumped, and associated equipment is not cleaned near ponds, streams, or wells; and
- Substance containers are disposed of properly at an appropriate landfill facility.

6.2 Muskrat Management Methods

6.2.1 Muskrat Control Through Habitat Modification (South Carolina DNR, 2003; University of Nebraska, 1994; Michigan State University Extension, 1998; USDA, 1991)

Mow regularly to remove food supply. Specifically, remove cattails, arrowhead, and other plants that grow on the fringe of the reservoir.

Implement an aquatic vegetation control program to reduce aquatic vegetation preferred by the muskrat for food and cover. Muskrat populations can be effectively managed by eliminating food sources. The vegetation control program can be achieved through several management approaches:

- ***Herbicides*** are widely used to control aquatic vegetation. Out of the 200 herbicides registered with the U.S. Environmental Protection Agency, only 8 are available for aquatic uses, and only 6 of those 8 are widely used (2 herbicides are limited to use in 17 western States' irrigation systems under Bureau of Reclamation control). Coordination with the state agency responsible for aquatic plant management is required to ensure that the appropriate herbicide is selected based on management goals and that herbicides are lawfully applied.
- ***Hand Removal*** of preferred muskrat vegetation can be implemented; however this method is labor-intensive and needs to be repeated frequently to keep vegetation, especially perennial plants, under adequate control. Hand removal can be combined with herbicide application.
- ***Mechanical Removal*** utilizes small and large weed harvesters to remove vegetation around the shoreline. This method achieves immediate vegetation control in small dams and does not carry water-use restrictions after treatment, unlike herbicide application. However, weed harvesters cannot be used in all environments—for example, obstructions may preclude harvester use. This method is usually higher in cost, slower, and less efficient than other available methods.

Manipulate water levels in the reservoir to create an undesirable habitat for the muskrat. A 2-foot drawdown in the reservoir during the winter months can be an effective muskrat management tool. Drawdown allows a dam specialist to identify and repair muskrat holes in the upstream slope (refer to Chapter 5.3.1 for burrow repair discussion), and may drive away resident muskrats, which need adequate water levels. It is recommended that muskrats be trapped and removed during the drawdown; however, trapping and relocation should be coordinated with the appropriate state agency, since a permit may be required.

A secondary benefit of water level manipulation is the potential drying and freezing of aquatic plants—the muskrat's primary food supply—as the plants are exposed to air. It should be noted that some aquatic plants are tolerant of drawdown and may actually increase after a drawdown; therefore, drawdown as a primary aquatic plant management method is not recommended.

6.2.2 Muskrat Control Through Trapping (University of Nebraska, 1994; South Carolina DNR, 2003)

The most effective types of traps for muskrat include the Conibear® traps No. 110 and 120, and leghold traps like the long spring No. 1, 1½ or 2, and similar coil spring traps (Figure 6-1 and 6-2). The Conibear® traps are preferred because they are effective in shallow and deep water settings, easy to set up, and kill the muskrat quickly, preventing escapes. The Conibear® and leghold traps are most effective when set close to the den entrance in the "runs" or trails carved into the reservoir bottom by the muskrat's hind feet. Runs can be easily seen in clear water, or can be felt with

Field testing in a 100-acre rice field (36 Conibear® 110 traps were set) and a 60-acre minnow pond (24 1½ leghold traps were set) yielded an effective muskrat removal rate of 93.3% and 87.5% for the Conibear® and leghold traps, respectively. All tripped traps were 100% effective.

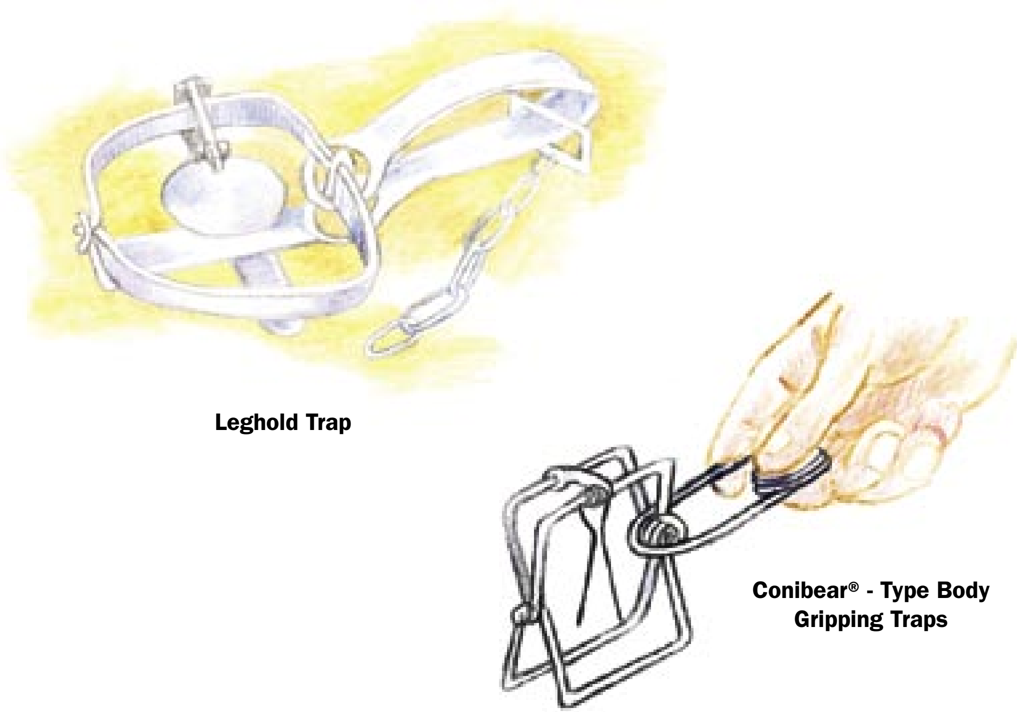


Figure 6-1. To capture muskrats, leghold traps should be set along runways, den openings, or natural resting areas. Conibear No. 110 traps should be set in the water.

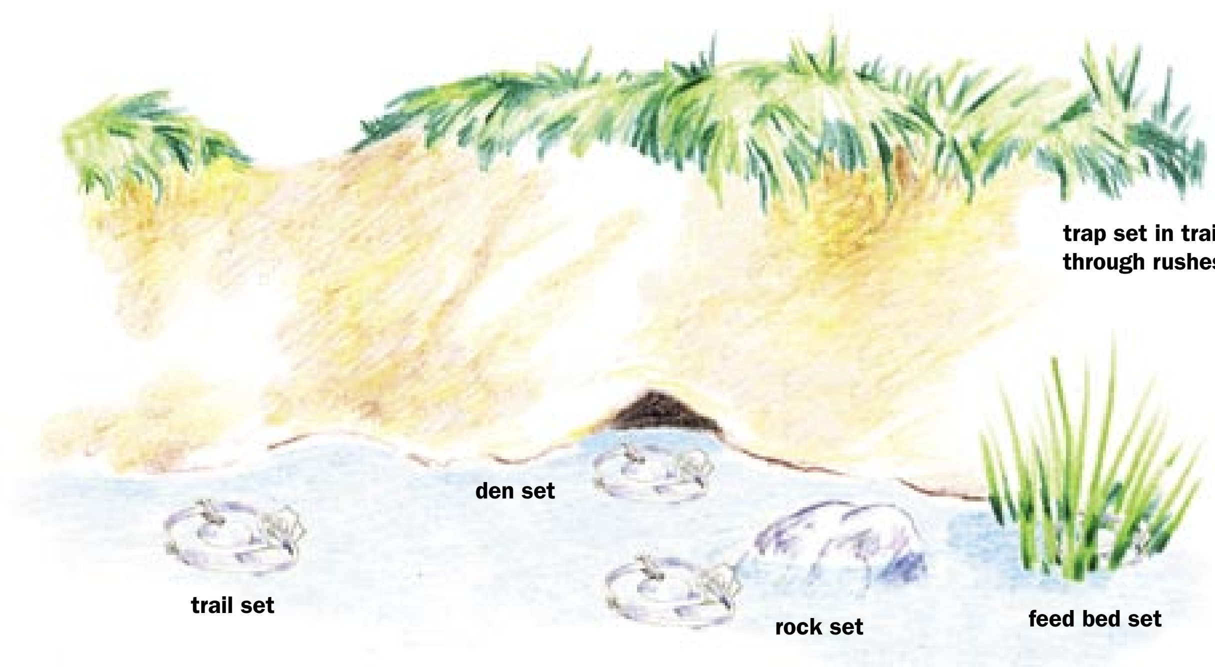


Figure 6-2. Muskrat traps can be effectively set in four locations. Bait traps with carrots, potatoes, sweet potatoes, or apples.

the hands or feet in murky or deep water. Poles can be used to anchor the trap in front of the den (Figure 6-3).

Where legal, homemade stovepipe traps can also be effective. This type of trap is cheap, simple, and easy to make, but it requires more time and effort to set. A trap can be constructed by forming sheet metal into a 6 x 6-inch rectangular box, 30 to 36 inches long with heavy-gauge hardware cloth or welded wire doors. The doors should be hinged at the top to allow entry from either end, but no escape out of the box. The trap should be set right up against the primary den entrance to be most effective.

6.2.3 Muskrat Control Through Fumigants (University of Nebraska, 1994)

No fumigants are registered for muskrat control.

6.2.4 Muskrat Control Through Toxicants (University of Nebraska, 1994)

Zinc phosphide (63% concentration) is the only toxicant Federally registered for muskrat control. To make a bait, vegetable oil is applied to cubes of apples, sweet potatoes, or carrots; the zinc phosphide is sprinkled on top; and the ingredients are mixed together thoroughly. The bait is then placed at the burrow entrance, on floating platforms (Figure 6-4), or on feeding houses. Zinc phosphide is a Restricted Use Pesticide and may therefore, only be purchased and applied by a certified pesticide applicator. Zinc phosphide should always be used as directed. Dam owners should contact the appropriate state wildlife agency regarding legality of toxicant use in their state.

Anticoagulants such as pivalyl, warfarin, diphacinone, and chlorophacinone have also been registered for muskrat control in some states. These anticoagulants come in the form of a "lollipop" made of grain, pesticide, and melted paraffin. As with zinc phosphide, anticoagulant baits can

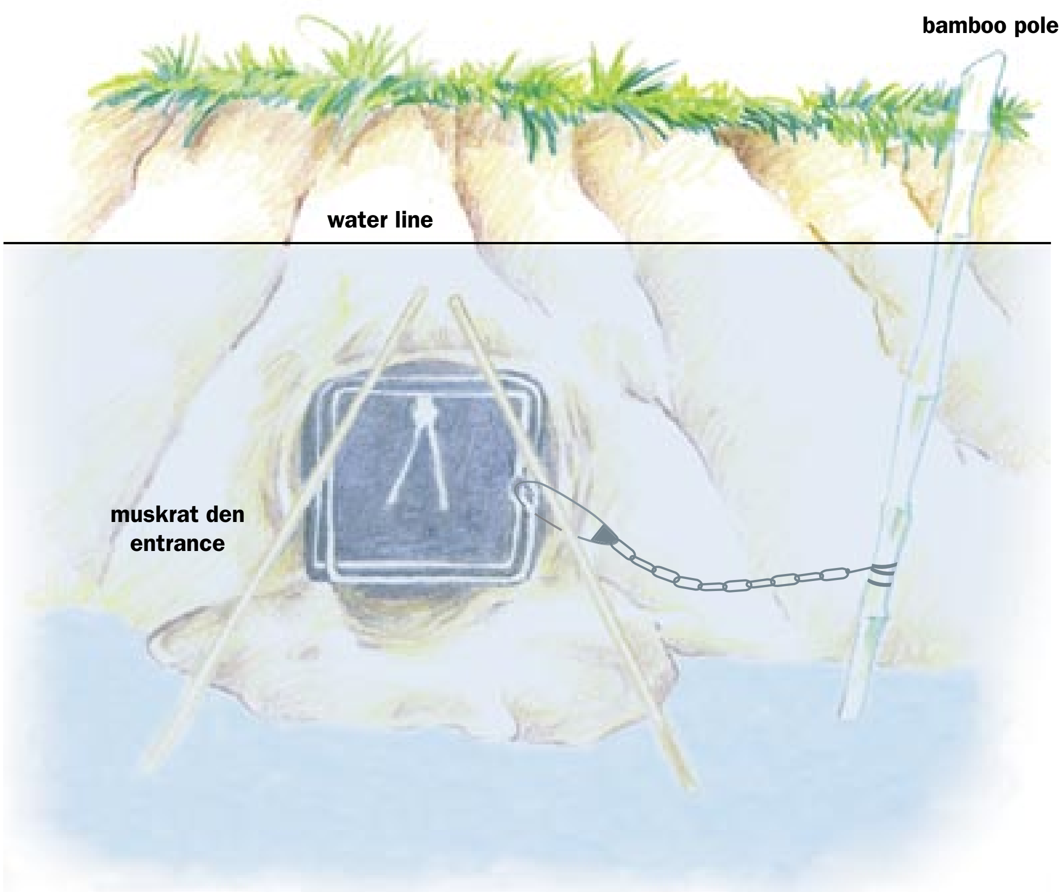


Figure 6-3. Pole set at muskrat den.

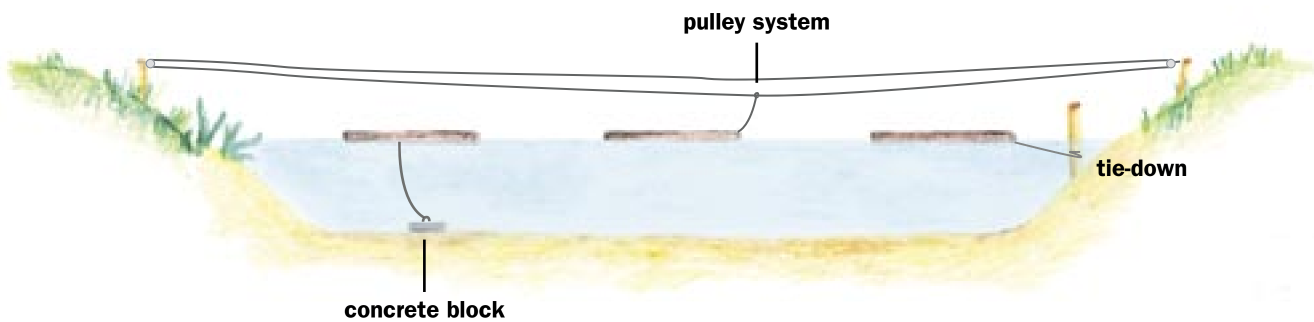


Figure 6-4. Toxicant bait platforms.

be placed at burrow entrances, on floating platforms, or on feeding houses. Dam owners should contact their state wildlife agency to see which, if any, anticoagulants are registered in their state.

6.2.5 Muskrat Control Though Frightening (University of Nebraska, 1994)

Frightening is not an effective method of muskrat control.

6.2.6 Muskrat Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for muskrat control.

6.2.7 Muskrat Control Through Shooting (University of Nebraska, 1994)

Shooting can be an effective method of eliminating a few individual muskrats. Hunting efforts are most successful at dawn and dusk. Dam owners should contact their state wildlife agency for information on hunting regulations and restrictions.

6.3 Beaver Management Methods

6.3.1 Beaver Control Through Habitat Modification (University of Nebraska, 1994; University of New Hampshire Cooperative Extension, 1997; USDA, 1994)

Clearing trees and shrubs near the reservoir will reduce potential food sources and habitat and may discourage beaver inhabitation of a dam. Daily destruction of existing dams and removal of dam construction material will sometimes cause existing beaver colonies or individuals to relocate.

Researchers in Louisiana found that deep water beaver dams could be removed more effectively than shallow water beaver dams, and that it was more effective to remove beaver dams in later summer rather than early or midsummer.

6.3.2 Beaver Control Through Trapping (University of Nebraska, 1994)

In most situations, trapping is the most effective and economical method of controlling beaver damage. Various types of traps can be used, but the Conibear® No. 330 is generally considered the most effective (refer to Figure 6-1 for trap types). It is designed primarily for water use, and works equally well in deep and shallow areas. Conibear®-type traps should be set on dry, solid ground to prevent injury to the person setting the trap. Once the trap is set, it can be moved to the water and anchored down with stakes. Traps can be effectively set in front of lodge entrances, in front of a hole in the beaver dam, or on underwater beaver trails.

Leghold traps (No. 3 double spring or larger) are also commonly used to capture beavers. This type of trap should be used with a drowning set attachment so that the captured beaver cannot escape. Proper placement is very important with leghold traps. They should be set just at the water's edge, slightly underwater, with the pan, jaws, and springs covered lightly with leaves or debris. There must be a cavity under the pan for the trap to properly trigger. Leghold traps are most effective when they are set slightly off-center on an underwater beaver trail.

Snares can also be used to capture beavers. The equipment costs less than trapping equipment, and snares can be set so that the beaver is caught alive and can then be relocated. Snares are frequently set under logs, near bank dens, and next to castor mounds.

Dam owners should contact their state wildlife agency regarding trapping regulations and seasons and regulations regarding live trapping and relocation.

6.3.3 Beaver Control Through Fumigants (University of Nebraska, 1994)

No fumigants are registered for beaver control.

6.3.4 Beaver Control Through Toxicants (University of Nebraska, 1994)

No toxicants are registered for beaver control.

6.3.5 Beaver Control Through Frightening (University of Nebraska, 1994)

Frightening is not an effective method of beaver control.

6.3.6 Beaver Control Through Repellents (University of Nebraska, 1994)

No repellents are Federally registered for beaver control.

6.3.7 Beaver Control Through Shooting

Shooting may also be used to remove small populations of beavers. If permitted by law, night shooting is most effective; however, hunting in the early evening and early morning hours can also be effective. Dam owners should contact their state wildlife agency for information on hunting regulations and restrictions.

6.4 Mountain Beaver Management Methods

The Point Arena mountain beaver is a Federally listed endangered subspecies and therefore subject to the provisions of the Endangered Species Act. This subspecies is found only in California. Dam owners in California who suspect that they have a mountain beaver problem should contact the USFWS and the California Department of Fish and Game for definitive species identification and management guidance.

6.4.1 Mountain Beaver Control Through Habitat Modification (University of Nebraska, 1994)

Removal of plants such as sword fern, bracken fern, or salal may reduce the attractiveness of a site to mountain beavers.

6.4.2 Mountain Beaver Control Through Trapping (University of Nebraska, 1994)

Trapping is an effective method of controlling mountain beavers. The Conibear® No. 110 is most commonly used (refer to Figure 6-1). The trap should be set in the main burrow entrance, anchored with three stakes. Trapping is most effective in warm months when mountain beaver are most active.

Live trapping is also possible using double-door wire mesh traps such as the Tomahawk. This method of trapping is recommended in areas where pets or livestock could accidentally be captured. The trap should be placed in the main burrow entrance with vegetation arranged along the inside and outside of the trap. The trap should be wrapped with black plastic and covered with soil to protect the captured mountain beavers from the weather. Captured animals should be placed in a dry burlap sack and euthanized or relocated to an appropriate location.

Dam owners should contact their state wildlife agency regarding trapping regulations and seasons and requirements for euthanasia or relocation.

6.4.3 Mountain Beaver Control Through Fumigants (University of Nebraska, 1994)

No fumigants are registered for mountain beaver control.

6.4.4 Mountain Beaver Control Through Toxicants (University of Nebraska, 1994)

No toxicants are Federally registered for mountain beaver control. Some toxicants may be registered in certain states, though, so dam owners should contact their state wildlife agency regarding this option.

6.4.5 Mountain Beaver Control Through Frightening (University of Nebraska, 1994)

Frightening is not an effective method of controlling mountain beaver.

6.4.6 Mountain Beaver Control Through Repellents (University of Nebraska, 1994)

Repellents are effective for controlling mountain beaver that are causing damage to trees/seedlings, but this method is not practical for preventing damage to earthen dams.

6.4.7 Mountain Beaver Control Through Shooting (University of Nebraska, 1994)

Mountain beavers are nocturnal animals that spend most of their time below ground; therefore, shooting is not a practical method of mountain beaver control.

6.5 Groundhog Management Methods

6.5.1 Groundhog Control Through Habitat Modification (Michigan State University Extension, 1998)

It is possible to discourage groundhog inhabitation by mowing vegetated areas of the earthen dam to remove cover.

6.5.2 Groundhog Control Through Trapping (USDA, 1991; University of Nebraska, 1994)

Trapping is an effective method of controlling limited populations of groundhogs. Steel leghold traps (No. 2) (refer to Figure 6-1) and live traps are both commonly used. Traps should be set at the main burrow entrance or on major travel lanes. Live traps, which can be purchased commercially or home-built, require bait such as apple slices, carrots, or lettuce. Groundhogs captured in live traps should be euthanized or relocated to a suitable habitat where they will not cause further damage.

Conibear® traps (110, 160, or 220) may also be used in certain situations (refer to Figure 6-1). They should not be used where they could capture domestic animals or livestock. Conibear® traps should be set in major travelways or at the main entrance of a burrow system. No bait is necessary.

Dam owners should consult with their state wildlife agency regarding specific trapping regulations and requirements for euthanasia or relocation.

6.5.3 Groundhog Control Through Fumigants (University of Nebraska, 1994)

Use of the commercial gas cartridge is the most common method of groundhog control. The cartridge is ignited and placed in the burrow with all other entrances sealed. As the cartridge burns, it produces carbon monoxide and other gases lethal to the groundhog. Gas cartridges are General Use Pesticides that can usually be purchased at local farm supply stores or pesticide dealers. They should be used with caution and in accordance with the directions on the label.

Aluminum phosphide is a Restricted Use Pesticide that may be applied by a certified pesticide applicator to control groundhogs. The legal application of aluminum phosphide may vary from state to state, so dam owners should consult with their state wildlife agency or state pesticide registration board before implementing this control method. Aluminum phosphide comes in tablet form. Two to four tablets should be inserted into the main burrow and then all burrow entrances must be tightly sealed. Aluminum phosphide should always be used as directed on the label.

Dam owners should consult with their state wildlife agency for information on state and local regulations regarding the use of fumigants to control groundhogs.

6.5.4 Groundhog Control Through Toxicants (University of Nebraska, 1994)

No toxicants are registered for groundhog control.

6.5.5 Groundhog Control Though Frightening (University of Nebraska, 1994)

Scarecrows or other effigies may be installed on or around the earthen dam to frighten groundhogs. This method of control works best if the scarecrows are moved regularly and if there is a high level of human activity around the dam.

6.5.6 Groundhog Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for groundhog control.

6.5.7 Groundhog Control Through Shooting (University of Nebraska, 1994)

Shooting is most effective if used as a follow-up to other control measures. Groundhogs are considered game animals in most states; therefore a hunting license may be required. Dam owners should consult with their state wildlife agency regarding specific hunting regulations and requirements.

6.6 Pocket Gopher Management Methods

6.6.1 Pocket Gopher Control Through Habitat Modification (Colorado State University Cooperative Extension, 2003)

Removal of forbs, through either chemical or mechanical treatment, may control some pocket gopher damage. This technique is generally effective only for individuals of the genera *Thomomys*, because they prefer the underground storage structure of forbs. Other species easily survive on grass and therefore will not likely be deterred by this technique.

6.6.2 Pocket Gopher Control Through Trapping (USDA, 1994; University of Nebraska, 1994)

Trapping can be extremely effective for pocket gopher control in small areas or when used in conjunction with toxicants. There are many types of traps available for pocket gopher control. The Macabee® gopher trap is the most popular, but other traps are also commonly used, including the Victor® Gopher Getter, the Death-Klutch 1 gopher and mole trap, and the Guardian gopher trap (Figures 6-5 through 6-8). Traps may be set in either the main tunnel or in one of the lateral tunnels (Figure 6-9). Trapping is most effective in the spring and fall, when gophers are pushing up new mounds, although it can be done year-round. Dam owners should consult with their state wildlife agency regarding specific trapping regulations.

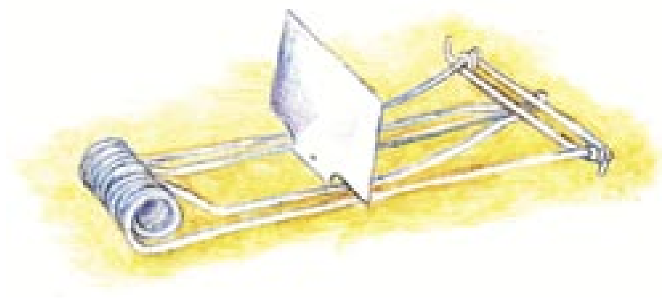


Figure 6-5. Macabee® gopher trap.

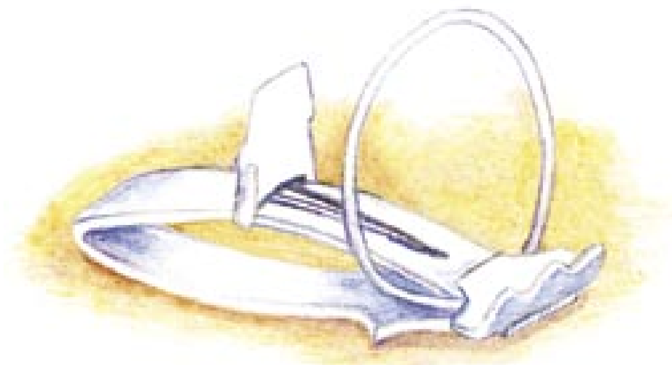


Figure 6-6. Victor® Gopher Getter.

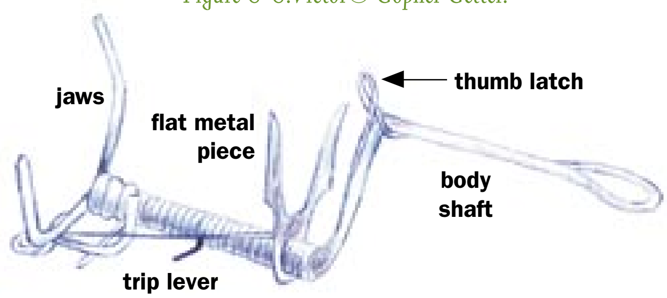


Figure 6-7. Death-Klutch 1 gopher and mole trap.

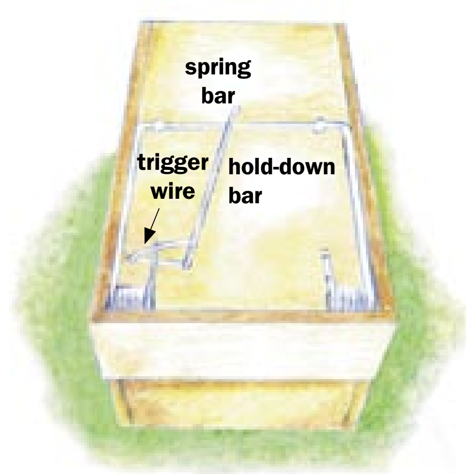


Figure 6-8. Guardian (California box-type) gopher trap.

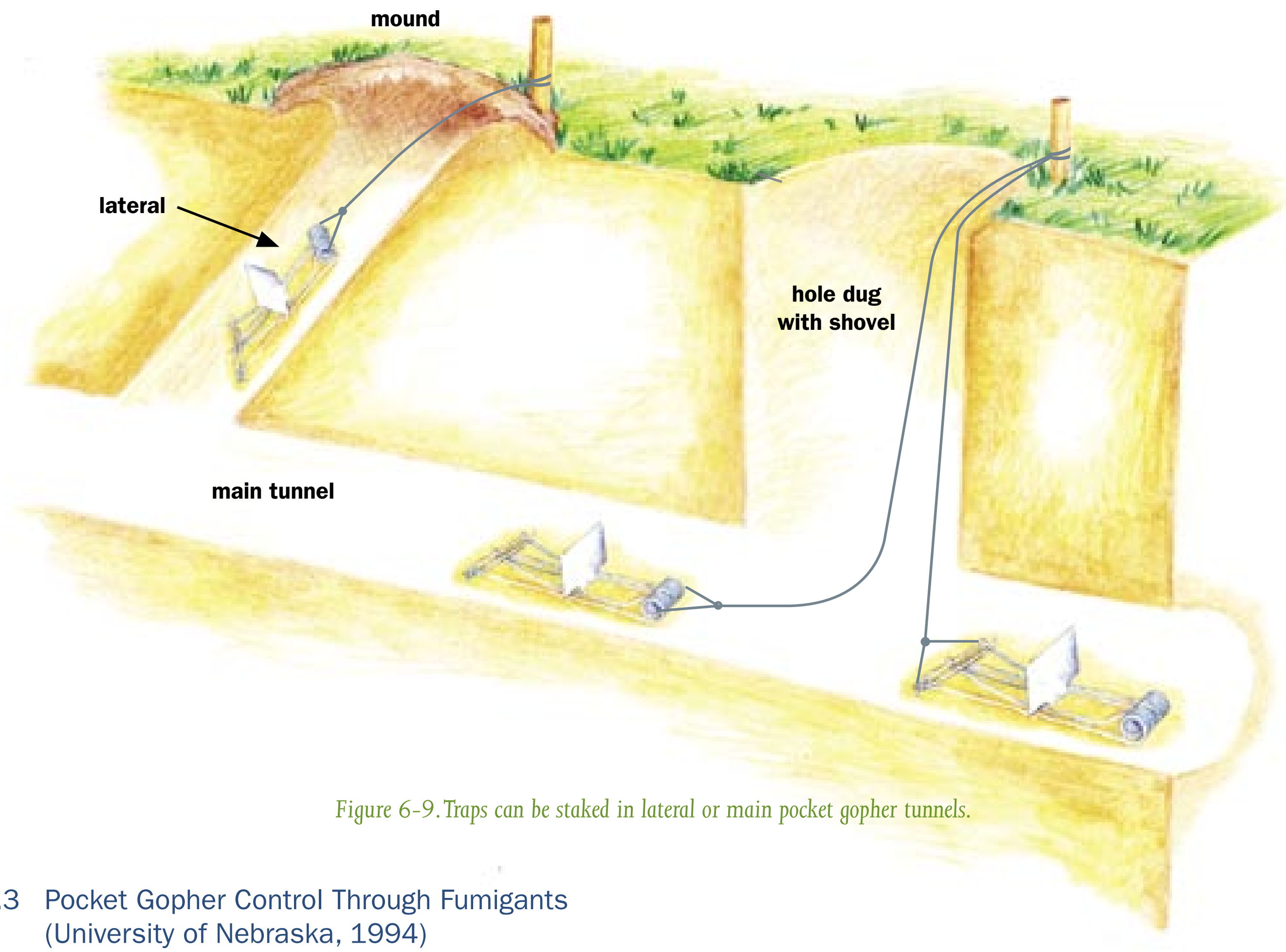


Figure 6-9. Traps can be staked in lateral or main pocket gopher tunnels.

6.6.3 Pocket Gopher Control Through Fumigants (University of Nebraska, 1994)

Aluminum phosphide and gas cartridges are both Federally registered for pocket gopher control. They are generally not effective though because the gas moves slowly through the tunnel system, allowing the fumigant to diffuse through the soil and escape to the surface. Carbon monoxide from automobile exhaust has proven more effective because of its greater volume and pressure. To implement this method of control, connect a hose or pipe to the engine exhaust and place it in a burrow opening near a fresh soil mound. Tightly pack soil around the hose or pipe and allow the engine to run for at least 3 minutes. This method is generally 90% effective and requires no federal registration. Dam owners should consult with their state wildlife agency for information on state and local regulations regarding fumigants.

6.6.4 Pocket Gopher Control Through Toxicants (University of Nebraska, 1994)

Several rodenticides are currently registered for pocket gopher control. Strychnine alkaloid (0.3 to 0.5% active ingredient) on grain baits is the most widely used. It is classified as a Restricted Use Pesticide and can only be sold to and used by a certified pesticide applicator. Applying 1 to 2 pounds per acre of 0.3 to 0.5% strychnine alkaloid grain with a burrow builder should provide an 85% to 95% reduction in the pocket gopher population. Zinc phosphide (2%) is also a registered toxicant for pocket gopher control, though it is less effective than strychnine. Additionally,

Carbon monoxide is generally 90% effective for pocket gopher control and requires no Federal registration.

two anticoagulants (chlorophacinine and diphacinone) are registered for pocket gopher control. Bait can be placed in a pocket gopher burrow system by hand, using a special hand-operated bait dispenser probe or with a mechanical burrow builder (Figures 6-10 and 6-11).

The first step to hand baiting with the bait dispenser is finding the main burrow, which is generally located 12 to 18 inches away from a plugged mound. Once the main burrow is located, place the probe over the burrow and push down until there is decreased resistance on the probe. Then push the button on the bait dispenser to release a metered dose of bait. For best results, each burrow should be baited in two or three locations.

Properly applied, strychnine alkaloid can provide an 85% to 95% reduction in a pocket gopher population.

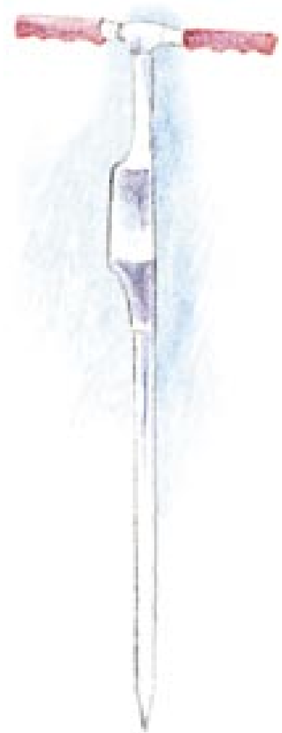


Figure 6-10. Effective baiting with a bait dispenser requires accurately finding the pocket gopher burrow. Use the probe to detect the main burrow, which is usually on the plug-side of the mound, 8-18 inches away from the plug (USDA, 1994).

The burrow builder is a tractor-drawn device that mechanically delivers bait underground. As the burrow builder moves along, it makes an artificial burrow, dispenses the bait into the newly formed burrow, and then closes up the hole. Artificial burrows should be constructed at depths similar to those constructed by pocket gophers in the area.

All toxicant products should be used as directed on the label. Dam owners should consult with their state wildlife agency regarding legality of toxicant use in their state before implementing any control measures.

6.6.5 Pocket Gopher Control Through Frightening

No frightening methods are effective for pocket gopher control.

6.6.6 Pocket Gopher Control Through Repellents (University of Nebraska, 1994; Witmer et al., 1995)

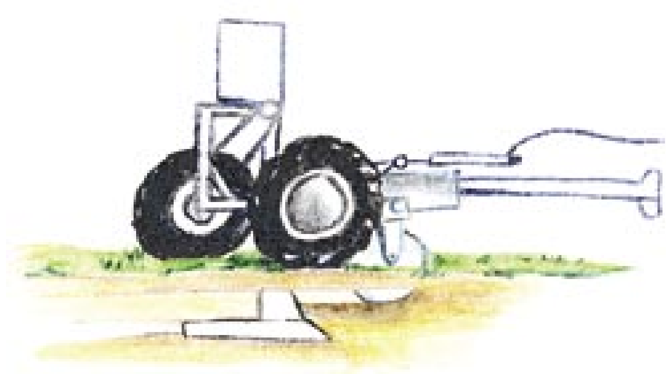


Figure 6-11. A burrow builder mechanically dispenses bait into constructed burrows. Adequate soil moisture is needed to form effective burrows. Adequate soil can be compressed in the hand and rolled gently without crumbling (USDA, 1994).

Repellents may be used to discourage pocket gopher inhabitation, although the effectiveness of this method is still in question. Initial testing has shown that some predator odors, such as coyote or bobcat urine, may effectively repel pocket gophers. Additionally, the mole plant (*Euphoriba lathyrus*), also known as the caper spurge or gopher purge, and the castor-oil plant (*Ricinus lathyrus*) have both been promoted as gopher repellents, although there is no scientific evidence to support this claim. Use of these plants is not recommended because they are poisonious to humans and pets, and can grow thickly, obscuring the dam.

6.6.7 Pocket Gopher Control Through Shooting (University of Nebraska, 1994)

Shooting pocket gophers is usually not a practical option because they spend most of their time below ground.

6.7 North American Badger Management Methods

6.7.1 North American Badger Control Through Habitat Modification (University of Nebraska, 1994; Texas Wildlife Damage Management Service, 1998)

Rodent control will alleviate most problems associated with badger damage. Badgers commonly prey on ground squirrels, pocket gophers, and prairie dogs. If this food source is eliminated, then damage from badger predation will be reduced and the badger will often move elsewhere in search of food. Dam owners should refer to sections of this manual pertaining to management of ground squirrels, pocket gophers, and prairie dogs for rodent control guidance.

6.7.2 North American Badger Control Through Trapping (University of Nebraska, 1994; Texas Wildlife Damage Management Service, 1998)

Badgers can often be removed from an area through the use of cage traps, leghold traps, or snares placed near the entrance of an active den. Cage traps require bait, such as a dead chicken or large rodent. After a badger is caught alive, it should be euthanized or relocated to an area where it will not cause further damage.

Leghold traps (No. 3 or 4) are most effective if attached to a drag such as a strong limb or fence post. If leghold traps are staked into the ground, it is likely that the badger will dig out the trap and escape.

Snaring involves setting a steel-cable loop in an animal's path to capture it by the neck, body, or leg. Snares are lightweight, compact, easy to set, low-cost, and they offer a high degree of human safety. Ready-made snares and snare components may be purchased from trapping suppliers. They must be attached to a solid object so the captured animal cannot escape. Snares should not be set where they could capture pets or livestock.

Dam owners should contact their state wildlife agency regarding trapping regulations.

6.7.3 North American Badger Control Through Fumigants (University of Nebraska, 1994)

No fumigants are registered for badger control.

6.7.4 North American Badger Control Through Toxicants (University of Nebraska, 1994)

No toxicants are registered for badger control.

6.7.5 North American Badger Control Through Frightening (University of Nebraska, 1994)

Badgers may be discouraged from inhabiting an area if high-intensity lights are installed and used at night.

6.7.6 North American Badger Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for badger control.

6.7.7 North American Badger Control Through Shooting (University of Nebraska, 1994)

Shooting can be an effective method of controlling small populations of badgers. Early morning, late evening, and after dark are the best times for hunting. Where legal, spotlights can be an effective tool for hunting at night. Dam owners should contact their state wildlife agency regarding hunting regulations and restrictions.

6.8 Nutria Management Methods

6.8.1 Nutria Control Through Habitat Modification (University of Nebraska, 1994; USDA, 1991)

Nutria can be discouraged from inhabiting an area by eliminating brush, trees, thickets, and weeds, which provide food and cover. Cleared vegetation should be burned or removed.

In certain situations, water level manipulation may be another damage control option. Dropping water levels in the summer and raising water levels in the winter will cause stress to nutria populations and may encourage them to relocate. The viability of this option is dependent upon reservoir useage (e.g., water spray, recreation, etc.) and owner willingness. In addition, lowering the water level has not yet been proven effective by researchers, but it is a tool to consider as part of a comprehensive nutria management strategy.

6.8.2 Nutria Control Through Trapping (University of Nebraska, 1994)

Trapping is a very effective method of controlling nutria. Leghold traps are most commonly used. Most trappers prefer double longspring traps (No. 11 or 2), but the No. 1 ½ coilspring, No. 3 double longspring, and soft-catch fox traps are also effective. Traps should be set just under the water where an active nutria trail enters the reservoir. The trap should be staked to the ground just off to the side of the trail and covered with leaves or other debris. To increase effectiveness, traps should be baited with chunks of apples, carrots, sweet potatoes, or watermelon rinds. In deep water, a drowning set should be used. If a nutria is captured alive in shallow water, then it should be disposed of humanely.

Single- or double-door live traps may be used to capture nutria. The cage should be at least 9 x 9 x 32 inches in size. Place the trap along active trails and bait with sweet potatoes or carrots. Captured nutria should be humanely destroyed.

Conibear® traps (No. 220-2, 160-2, and 330-2) are also commonly used to reduce nutria populations. These traps should be set on trails, at den entrances, in culverts, or in narrow waterways. They should not be used in areas frequented by children, domestic pets, or desirable wildlife species.

Snaring is another option for capturing nutria. Snaring involves setting a steel-cable loop in an animal's path to capture it by the neck, body, or leg. Snares constructed with 3/32-inch flexible stainless steel wire or galvanized aircraft cable are suitable for catching nutria. They should be set along trails, travel routes, feeding lanes, or bank slides.

Dam owners should contact their state wildlife agency regarding trapping regulations.

6.8.3 Nutria Control Through Fumigants (University of Nebraska, 1994)

No fumigants are registered for nutria control.

6.8.4 Nutria Control Through Toxicants (University of Nebraska, 1994)

Zinc phosphide is the only toxicant registered for nutria control. It is a Restricted Use Pesticide that must be purchased and applied by a certified pesticide applicator. The zinc phosphide is mixed with bait, such as apples, carrots, or sweet potatoes, and then the bait is placed in waterways, ponds, and ditches where permanent standing water and recent signs of nutria activity are found. Do not place bait directly in the water, but rather on floating rafts (anchored to the bottom or tied to the shore as depicted on figure 6-4), small islands, floating logs, or exposed tree stumps. Ground baiting is not recommended because humans and nontarget animals may be exposed to the toxicant.

Prebaiting increases the effectiveness of this control method. Apply corn oil to chunks of apples, carrots, or sweet potatoes and place the prebait at the designated baiting station. The station should be prebaited for several nights. Observe the station to ensure that nutria, rather than nontarget animals, are taking the bait. Once the nutria are accustomed to eating the prebait, the zinc-phosphide treated bait can be applied. The toxic bait should be applied until no more bait is being taken. Dead nutria that have been exposed to zinc phosphide should be collected and disposed of by deep burial or burning to prevent zinc phosphide exposure to domestic and wild scavengers.

6.8.5 Nutria Control Through Frightening (University of Nebraska, 1994)

Harassment may temporarily deter nutria from inhabiting an area. Loud noises and high-pressure water sprays have worked in some cases. As a long-term control method, however, frightening is not an effective or practical option.

6.8.6 Nutria Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for nutria control.

In certain areas, legal hunting with a shotgun or small caliber rifle has reduced nutria populations by 80%.

6.8.7 Nutria Control Through Shooting (University of Nebraska, 1994)

Shooting is an effective method of controlling nutria. This method is most effective at night with a spotlight, although it should be noted that this technique is not legal in all states. Shooting can be effective when carried out at bait stations, from boats, or from the bank. Dam owners should contact their state wildlife agency for information on hunting regulations and restrictions.

6.9 Prairie Dog Management Methods

Because other animals frequently inhabit prairie dog towns, including the Federally protected burrowing owl and black-footed ferret, dam owners need to be particularly cautious when taking action to control prairie dogs. In regions and habitats where burrowing owls and black-footed ferrets are known to live, dam owners should coordinate with their state wildlife agency and the USFWS to determine whether either of these species is present; field surveys by qualified biologists may be required. Burrows that have feathers or white droppings at the mouth probably contain burrowing owls. Black-footed ferrets are secretive animals, and since it can be very difficult to verify their existence in a particular burrow system, it is best to contact the USFWS and the state wildlife agency for guidance on completing a black-footed ferret survey (University of Nebraska, 1994). If either of these species is present, the dam owner must contact the USFWS and their state wildlife agency for management guidance.

It is also important to remember that the Utah prairie dog, one of the four prairie dog species found in the United States, is listed as a Federally threatened species and is therefore subject to the provisions of the Endangered Species Act. As the name implies, the Utah prairie dog is found only in Utah. Dam owners in Utah who suspect that they have a prairie dog problem should contact the USFWS and the Utah Division of Wildlife Resources for species identification and management guidance.

6.9.1 Prairie Dog Control Through Habitat Modification (University of Nebraska, 1994)

Installation of visual barriers may discourage prairie dogs from inhabiting an area. Prairie dogs prefer areas of low vegetation to provide a clear view of their surroundings and to improve their ability to detect predators. Objects such as fences or hay bales that are strategically placed to block prairie dog views may reduce suitability of the habitat.

6.9.2 Prairie Dog Control Through Trapping (USDA, 1991)

Trapping may be used to control prairie dogs, but it is quite labor intensive and therefore only practical for removing small populations. Cage traps for live capture, Conibear® traps (No. 110), and leg-hold traps are often used. Cage traps are most effective in early spring. They should be baited with oats flavored with corn or anise oil. Dam owners should consult with their state wildlife agency for guidance on releasing captured prairie dogs. Conibear® and leg-hold traps should be set in burrow entrances. They do not require bait. Dam owners should consult with their state wildlife agency regarding specific trapping regulations.

6.9.3 Prairie Dog Control Through Fumigants (University of Nebraska, 1994)

Fumigants can be used to control prairie dogs in some situations, however this method is often costly, time-consuming, and particularly hazardous to other wildlife. Fumigation is most effective as a follow-up to toxic baits. It should not be used in burrows where nontarget species are thought to be present.

Aluminum phosphide can reduce prairie dog populations by 85% to 95%.

Aluminum phosphide is a registered fumigant for control of burrowing rodents, including prairie dogs. It is a Restricted Use Pesticide and therefore must be purchased and applied by a certified pesticide applicator. Aluminum phosphide comes in tablet form. One tablet should be inserted into each burrow and then the burrow entrance should be tightly plugged with soil. When used correctly, aluminum phosphide typically provides an 85% to 95% reduction in prairie dog populations. The legal application of aluminum phosphide may vary from state to state so dam owners should consult with their state wildlife agency or state pesticide registration board before implementing this control method.

Gas cartridges may also be used to control prairie dogs. Gas cartridges are General Use Pesticides that can usually be purchased at local farm supply stores or pesticide dealers. When ignited, a gas cartridge will produce carbon monoxide, carbon dioxide, and other gases that are toxic to the prairie dog. The cartridge should be lit before it is placed in the burrow. Once it has been inserted, the burrow should be immediately plugged with soil. Gas cartridges should be used with caution and in accordance with the directions on the label. When used correctly, gas cartridges can provide a 95% reduction in prairie dog populations.

Gas cartridges can provide a 95% reduction in prairie dog populations.

Dam owners should consult with their state wildlife agency for information on state and local regulations regarding gas cartridges and the use of fumigants.

6.9.4 Prairie Dog Control Through Toxicants (University of Nebraska, 1994)

Baiting with a toxicant is generally the most economical and effective method of controlling prairie dogs. Zinc phosphide bait is currently the only registered and legal toxicant available for prairie dog control. It is available in 2% zinc phosphide-treated grain bait and pellet formulations. It is a Restricted Use Pesticide, which means that it is only available for sale to and use by certified pesticide applicators. Zinc phosphide baits can be applied from July 1 through January 31, though it is best to apply the baits in late summer and fall when prairie dogs are most active and there is no green forage available.

Zinc phosphide can be 75% to 85% successful in controlling prairie dogs when used correctly.

A prebait must be applied to the burrows before the toxic bait. The prairie dogs will become accustomed to eating the non-toxic grains, which will increase the effectiveness of the toxic bait. The prebait and the toxic bait may be applied by hand or by a mechanical bait dispenser attached to an all-terrain vehicle, motorcycle, or horse.

6.9.5 Prairie Dog Control Through Frightening (University of Nebraska, 1994)

Frightening is not an effective method of control for prairie dogs.

6.9.6 Prairie Dog Control Though Repellents (University of Nebraska, 1994)

No repellents are Federally registered for prairie dog control.

6.9.7 Prairie Dog Control Through Shooting (University of Nebraska, 1994)

Continuous shooting of prairie dogs can remove about 65% of the population annually, but it is generally not a practical or cost-effective method of control. Shooting is most effective in spring because it can disrupt breeding. Dam owners should consult with their state wildlife agency regarding specific hunting regulations and requirements.

6.10 Ground Squirrel Management Methods

The northern Idaho ground squirrel, one of 23 ground squirrel species in the United States, is Federally listed as a threatened species and is therefore subject to the provisions of the Endangered Species Act. The northern Idaho ground squirrel is found in limited distribution in the northwest. Dam owners in that region who experience problems with ground squirrels should contact the USFWS and their state wildlife agency for species identification and management guidance.

The New Mexico and Nebraska Dam Safety Offices have set up roosts in the dam environment to support raptors such as red-tailed hawks to provide predator control of small rodents.

6.10.1 Ground Squirrel Control Through Habitat Modification (USDA, 1991)

Routine weed control and vegetative management may limit some ground squirrel damage, but the effectiveness of this method is usually limited.

6.10.2 Ground Squirrel Control Through Trapping (University of Nebraska, 1994)

Trapping is a labor-intensive control method, and therefore it is generally only useful for removing small populations of ground squirrels. Jaw traps (No. 1 or No. 0), box or cage traps, and Conibear® traps (No. 110 or No. 110-2) may be used (refer to Figure 6-1). Generally, one trap is needed for every 10 to 15 squirrels present. Traps should be set on trails or near burrow entrances. Box or cage traps require bait, such as fruit, vegetables, peanut butter, or grain; baiting is not necessary with jaw traps or Conibear® traps. Dam owners should contact their state wildlife agency for information on state and local trapping regulations.

6.10.3 Ground Squirrel Control Through Fumigants (University of Nebraska, 1994)

Aluminum phosphide and gas cartridges are both registered fumigants for ground squirrel control. Fumigants work best for light squirrel infestations limited to a few acres. This method is most effective in the spring, when ground squirrels have just emerged from hibernation.

Aluminum phosphide is a Restricted Use Pesticide that comes in tablet form. This fumigant can only be purchased and applied by a certified pesticide applicator. One tablet should be placed in each burrow entrance and then the burrow should be plugged with soil to form an air-tight seal. The legal application of aluminum phosphide may vary from state to state so dam owners should consult with their state wildlife agency or state pesticide registration board before implementing this control method.

Gas cartridges are General Use Pesticides that can usually be purchased at local farm supply stores or pesticide dealers. When ignited, a gas cartridge will produce carbon monoxide, carbon dioxide, and other gases that are toxic to ground squirrels. The cartridge should be lit before it is placed in the burrow. Once it has been inserted, the burrow should be immediately plugged with soil. Gas cartridges should be used with caution and in accordance with the directions on the label. Dam owners should consult with their state wildlife agency for information on state and local regulations regarding gas cartridges and the use of fumigants.

6.10.4 Ground Squirrel Control Through Toxicants (University of Nebraska, 1994)

Zinc phosphide and two anticoagulants, chlorophacinone and diphacinone, are currently registered for ground squirrel control.

When used correctly, zinc phosphide can result in an 85% to 95% reduction in ground squirrel population.

Zinc phosphide is a Restricted Use Pesticide, which means that it can only be purchased and applied by a certified pesticide applicator. It is a single-dose toxicant delivered on oat baits. The ground squirrels should be exposed to an untreated prebait several days before using the toxic grain. Bait can be delivered by hand or mechanically dispensed.

Chlorophacinone and diphacinone are two anticoagulant baits that are registered in some states under various trade names. A continuous supply of bait must be applied for 4 to 9 days for the toxicant to be effective. The bait is usually delivered in a bait box, which can be made of rubber tires or metal, plastic, or wood containers. The commonly used PVC Inverted-T anticoagulant bait station consists of 4-inch sections of plastic irrigation pipe formed into an inverted "T" configuration (Figure 6-12). Dam owners should contact

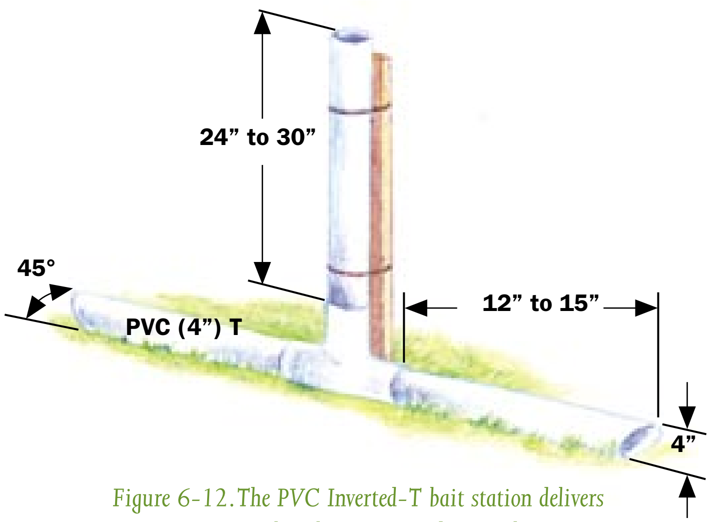


Figure 6-12. The PVC Inverted-T bait station delivers anticoagulant bait to ground squirrels.

their state wildlife agency for information on anticoagulants that may be available for use.

All products should be used as directed. Dam owners should consult with their state wildlife agency regarding legality of toxicant use in their state.

6.10.5 Ground Squirrel Control Through Frightening (University of Nebraska, 1994)

Frightening is not an effective method of control for ground squirrels.

6.10.6 Ground Squirrel Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for ground squirrel control.

6.10.7 Ground Squirrel Control Through Shooting (University of Nebraska, 1994)

Shooting may be used to remove small populations of ground squirrels, although it is an expensive and time-consuming method of control. Dam owners should consult with their state wildlife agency regarding specific hunting regulations and requirements

6.11 Armadillo Management Methods

6.11.1 Armadillo Control Through Habitat Modification (University of Nebraska, 1994)

It is possible to discourage armadillos from burrowing in an earthen dam by implementing the following habitat mitigation techniques:

- Remove brush or other cover to reduce the amount of suitable habitat.
- Apply soil insecticides to remove insects and other invertebrates that make up the majority of the armadillo's diet.

6.11.2 Armadillo Control Through Trapping (University of Nebraska, 1994)

Trapping can be an effective method of managing armadillos. Live or box traps (10 x 12 x 32-inch), such as the Havahart or Tomahawk, work best. A trap's effectiveness can be enhanced by adding "wings" (1 x 4-inch or 1 x 6-inch boards about 6 feet long) to funnel the animal into the trap (Figure 6-13). The best locations to set traps are along pathways to burrows and along fences or other barriers where armadillos may travel. Conibear® (No. 220) or leghold traps (No. 1 or 2) may also be used (refer to Figure 6-1). These types of traps should be placed at the entrance of a burrow.

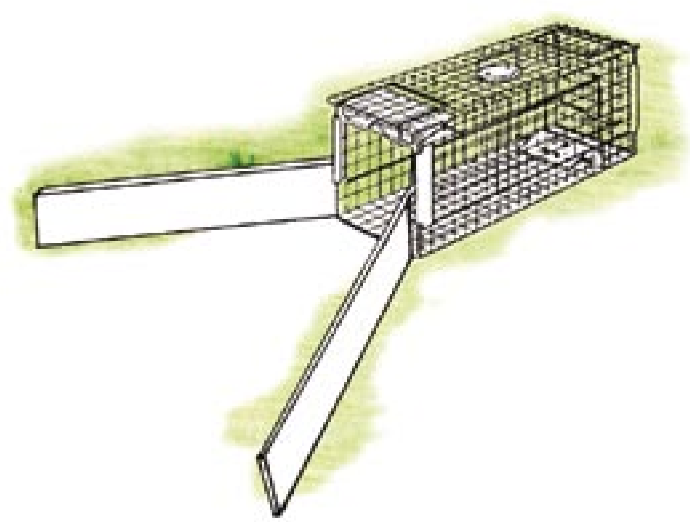


Figure 6-13. The effectiveness of cage traps can be enhanced by adding "wings" to funnel the armadillo into the trap.

6.11.3 Armadillo Control Through Fumigants (University of Nebraska, 1994)

No fumigants are Federally registered for armadillo control. However, there are some fumigants that are effective and that may be legal in certain states. Dam owners should consult their state wildlife agency regarding fumigants that may be legal in their area.

6.11.4 Armadillo Control Through Toxicants (University of Nebraska, 1994)

No toxicants are registered for armadillo control.

6.11.5 Armadillo Control Through Frightening

Frightening is not an effective method of armadillo control.

6.11.6 Armadillo Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for armadillo control.

6.11.7 Armadillo Control Through Shooting (University of Nebraska, 1994)

Shooting is an effective method of controlling armadillos. The best time to shoot is during twilight hours or at night when armadillos are most active. Dam owners should consult with their state wildlife agency regarding specific hunting regulations and requirements.

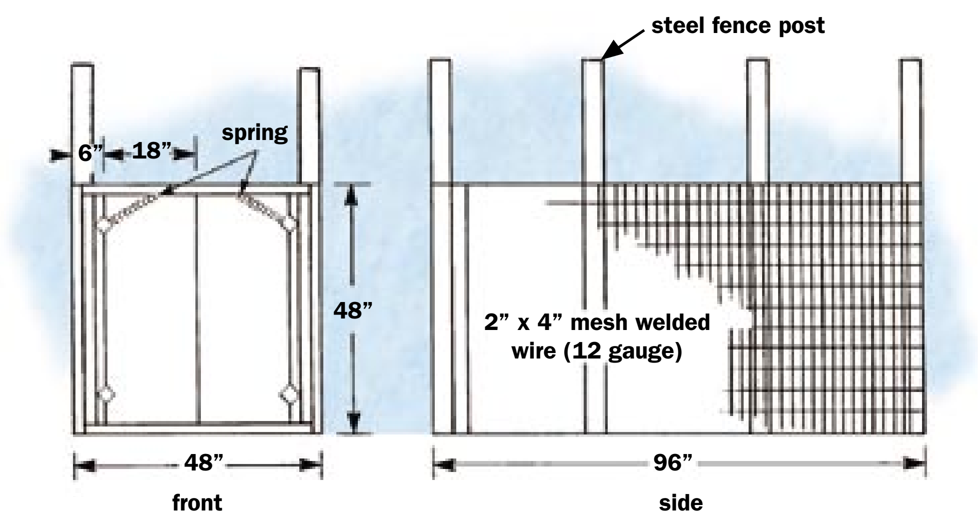
6.12 Livestock (Cow, Sheep, Horse, Pig, and Wild Pig) Management Methods

6.12.1 Livestock Control Through Habitat Modification (USDA, 1991)

Providing a water source away from the earthen dam may help reduce livestock damage near the dam, since livestock are often at the dam in search of drinking water.

6.12.2 Livestock Control Through Trapping (USDA, 1991; University of Nebraska, 1994)

Trapping is quite effective for wild pigs. Stationary corral-type traps and box traps are commonly used (Figure 6-14). They are most effective in summer when acorns and other



	2” x 4” x 24’ wood	8	6” steel fence posts
	36” x 48” x 3/4” plywood	4 lbs	16-penny nails
	36’ x 2” x 4” mesh welded wire	1 lbs	12-penny nails
4	6” strap hinges	2 lbs	1 1/2” staples
2	12” screen door springs	1	100 12-gauge wire

Figure 6-14. Stationary hog trap.

preferred natural foods are not available. Traps should be baited with grains, fruits, or vegetables. The traps may be placed anywhere that wild pigs concentrate.

6.12.3 Livestock Control Through Fumigants (USDA, 1991)

Fumigants are not suitable for livestock control.

6.12.4 Livestock Control Through Toxicants (USDA, 1991)

Toxicants are not suitable for livestock control.

6.12.5 Livestock Control Through Frightening (USDA, 1991)

Frightening devices such as animated scarecrows or firecrackers may temporarily deter livestock from inhabiting an area, but these techniques generally do not provide a long-term solution to livestock damage.

6.12.6 Livestock Control Through Repellents (USDA, 1991)

Repellents are not suitable for livestock control.

6.12.7 Livestock Control Through Shooting (USDA, 1991)

Shooting may be an effective method of removing a small population of nuisance livestock; however, hunting is generally only permitted for wild animals such as pigs. Dam owners should contact their state wildlife agency regarding hunting regulations and restrictions.

6.13 Crayfish Management Methods

6.13.1 Crayfish Control Through Habitat Modification (Virginia Cooperative Extension, 2001a).

Damage may be prevented by stocking the reservoir with natural enemies of crayfish, such as trout, bass, catfish, and large bluegills. These species will eat the crayfish, which will reduce the overall crayfish population and decrease the number of burrows.

6.13.2 Crayfish Control Through Trapping (University of Nebraska, 1994)

Wire cage traps baited with fish or meat can be used to catch crayfish.

6.13.3 Crayfish Control Through Fumigants (University of Nebraska, 1994)

No fumigants are Federally registered for crayfish control.

6.13.4 Crayfish Control Through Toxicants (University of Nebraska, 1994)

No toxicants are Federally registered for crayfish control. Some states, however, have regulations that allow application of certain insecticides for crayfish burrow treatment. Dam owners should consult with their state wildlife agency regarding the legality of toxicants in their state.

6.13.5 Crayfish Control Through Frightening

Frightening is not an effective method of controlling crayfish.

6.13.6 Crayfish Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for crayfish control.

6.13.7 Crayfish Control Through Shooting

Shooting is not a suitable method of controlling crayfish.

6.14 Coyote Management Methods

6.14.1 Coyote Control Through Habitat Modification (USDA, 1991)

Proper vegetative management (mowing and brush removal) and rodent control will often discourage coyotes from digging in earthen dams.

6.14.2 Coyote Control Through Trapping (University of Nebraska, 1994)

Steel leg-hold traps (No. 3 and 4) are often used for coyote removal. Effective use of these traps for coyote control generally requires a great deal of experience and training.

Dam owners should contact their state wildlife agency for guidance on trapping nuisance coyotes.

Snaring is another method of removing coyotes. Snaring involves setting a steel-cable loop in an animal's path to capture it by the neck, body, or leg. Snares are light-weight, compact, easy to set, low-cost, and they offer a high degree of human safety. In one study, they were proven to be more effective than leg-hold traps for coyote control. Snares are usually made of a 2.5- to 10-foot long piece of galvanized aircraft cable with a slide lock that forms a loop. Snares should be set along known coyote trails. They must be attached to a solid object so that the captured animal cannot escape. Snares should not be set where they could capture pets or livestock. Snares are not legal in all states so dam owners should consult with their state wildlife agency before choosing this control method. Once caught, coyotes should be humanely destroyed.

6.14.3 Coyote Control Through Fumigants (University of Nebraska, 1994)

Gas cartridges are the only registered fumigant for coyote control. Gas cartridges are General Use Pesticides that can usually be purchased at local farm supply stores or pesticide dealers. When ignited and placed in the den, a gas cartridge will produce carbon monoxide, carbon dioxide, and other gases that are toxic to the coyote. Gas cartridges should be used with caution and in accordance with the directions on the label. Dam owners should consult with their state wildlife agency regarding state and local regulations on gas cartridges and the use of fumigants.

6.14.4 Coyote Control Through Toxicants (University of Nebraska, 1994)

The only toxicant registered for coyote control is sodium cyanide used in an M-44 ejector device. The M-44 is a spring-activated device that expels a sodium cyanide capsule into the animal's mouth. The M-44 device should be set along the sides of trails or paths used by coyotes. This control method is most effective during cooler months. The M-44 sodium cyanide device is classified as a Restricted Use Pesticide and may only be used by USDA Animal Damage Control personnel and, in some states, certified pesticide applicators. The M-44 is not registered for use in all states so dam owners must consult their state wildlife agency before implementing this control measure.

6.14.5 Coyote Control Through Frightening (USDA, 1991)

Several types of frightening devices are available for coyote control, but these devices were designed for livestock protection and are not practical for protection of earthen dams.

6.14.6 Coyote Control Through Repellents (University of Nebraska, 1994)

No repellents have proven effective for coyote control.

6.14.7 Coyote Control Through Shooting (USDA, 1991)

Coyote hunting is often an effective method of control for livestock protection, but it is generally not practical for protecting earthen dams. If a dam owner decides to pursue this method of control, they must contact the state wildlife agency for information on hunting regulations.

6.15 Mole and Vole Management Methods

6.15.1 Mole and Vole Control Through Habitat Modification (University of Nebraska, 1994; USDA, 1991)

It is possible to discourage moles from burrowing in an earthen dam by implementing the following habitat modification techniques:

- Compact the soil with a roller to reduce soil moisture. This will reduce the habitat's attractiveness to moles.
- Apply insecticides to reduce food supply. Legal insecticides may vary by state so dam owners should contact their state wildlife agency for specific guidance.

6.15.2 Mole and Vole Control Through Trapping (University of Nebraska, 1994)

Trapping is the most effective method of reducing mole populations. Several traps are specifically designed for moles, including the Victor mole trap, Out O' Sight, and Nash (choker loop) mole trap. If used properly, any of these traps can be effective. Traps should be set in the surface runway where there is evidence of recent mole activity.

Trapping is generally not an effective method of reducing large vole populations because of prohibitive time and labor costs. Mouse snap traps may be used for control of a few individual voles. Traps should be set perpendicular to a runway with the trigger end in the runway. Voles are easiest to trap in the fall and late winter.

6.15.3 Mole and Vole Control Through Fumigants (University of Nebraska, 1994)

Both aluminum phosphide and gas cartridges are Federally registered for mole control. Aluminum phosphide is a Restricted Use Pesticide that comes in tablet form. One tablet should be placed in each burrow entrance and then the burrow should be plugged with soil to form an air-tight seal. The legal application of aluminum phosphide may vary from state to state so dam owners should consult with their state wildlife agency or state pesticide registration board before implementing this control method.

Gas cartridges are General Use Pesticides that can usually be purchased at local farm supply stores or pesticide dealers. When ignited, a gas cartridge will produce carbon monoxide, carbon dioxide, and other toxic gases. The cartridge should be lit before it is placed in the burrow. Once it has been inserted, the burrow should be immediately plugged with soil. Gas cartridges should be used with caution and in accordance with the directions on the label. Dam owners should consult with their state wildlife agency for information on state and local regulations regarding gas cartridges and the use of fumigants.

Fumigants are generally not effective for vole control. The vole burrow system is so complex and shallow that the fumigant easily escapes to the surface.

6.15.4 Mole and Vole Control Through Toxicants (University of Nebraska, 1994)

Strychnine alkaloid and chlorophacinone are both Federally registered for mole control. Strychnine alkaloid is a Restricted Use Pesticide that can only be purchased and applied by a certified pesticide applicator. However, since moles do not normally consume grain, strychnine alkaloid grain baits are seldom effective. Chlorophacinone is commercially available in pellet form under the name Orco Mole Bait. Researchers have found that this is a highly effective and easy to apply mole control technique. Dam owners should be aware, though, that two or more successive treatments are often required. If a dam owner chooses either of these methods of control, they should contact the state wildlife agency regarding the legality of toxicant use in their state.

Zinc phosphide is often used for vole control. Zinc phosphide is a single-dose toxicant available in pellet or grain bait formulas. Pellets or grain bait can be delivered to burrows by hand or mechanically dispensed. Zinc phosphide is a Restricted Use Pesticide, which must be purchased and applied by a certified pesticide applicator. Anticoagulant baits can also be used to reduce vole populations. Anticoagulants generally require several feedings and can take anywhere from 5 to 15 days to be effective. Bait can be delivered by hand, mechanically dispensed, or placed in various types of bait containers. Registration for anticoagulants varies by state.

All products should be used as directed. Dam owners should consult with their state wildlife agency regarding legality of toxicant use in their state.

6.15.5 Mole and Vole Control Through Frightening (University of Nebraska, 1994)

Frightening is not an effective method of control for moles or voles.

6.15.6 Mole and Vole Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for mole control.

Several repellents using thiram or capsaicin as the active ingredient are registered for vole control, but there is no evidence that these repellents are actually effective. Dam owners should contact their state wildlife agency or pesticide regulatory agency for information on available repellents in their state.

6.15.7 Mole and Vole Control Through Shooting (University of Nebraska, 1994)

Shooting is not an effective method of control for moles or voles.

6.16 River Otter Management Methods

6.16.1 River Otter Control Through Habitat Modification (University of Nebraska, 1994)

Habitat modification is generally not an effective method of control for river otters. Otters often share their environment with beavers, whose burrowing activity is detrimental to the earthen dam environment. Otters will often live in beaver burrows and dens and do not often dig their own dens. Before mitigating for the river otter, evaluate whether the damaging actions are caused by beaver so that the appropriate species is managed and proper preventive actions are implemented (as discussed in Chapters 4.0 and 5.0 of this manual).

6.16.2 River Otter Control Through Trapping (University of Nebraska, 1994)

Both Conibear (No. 220 and 330) and leghold (modified No. 1 ½ soft-catch and No. 11 double coilspring) traps have been successfully used to catch river otters. Traps should be placed underwater along river otter trails or on "pull-outs" where otters leave the water. Leghold traps can also be used out of the water along trails and peninsula crossings. River otter trapping is illegal in many states so dam owners should contact their state wildlife agency before initiating a trapping program.

6.16.3 River Otter Control Through Fumigants (University of Nebraska, 1994)

No fumigants are registered for river otter control.

6.16.4 River Otter Control Through Toxicants (University of Nebraska, 1994)

No toxicants are registered for river otter control.

6.16.5 River Otter Control Through Frightening (University of Nebraska, 1994)

Frightening has not proven to be an effective method of river otter control.

6.16.6 River Otter Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for river otter control.

6.16.7 River Otter Control Through Shooting (University of Nebraska, 1994)

Shooting is generally only effective for removing small populations of river otters. Dam owners should contact their state wildlife agency for information on hunting regulations and requirements.

6.17 Gopher Tortoise Management Methods

The gopher tortoise is a Federally listed threatened species and therefore subject to the provisions of the Endangered Species Act. The historic range of the gopher tortoise includes Alabama, Florida, Georgia, Louisiana, Mississippi, and South Carolina. Dam owners in those states who suspect that they have a gopher tortoise problem should contact the USFWS and their state wildlife agency for management guidance.

6.17.1 Gopher Tortoise Control Through Habitat Modification (University of Nebraska, 1994)

Habitat modification is generally not an effective method of gopher tortoise control.

6.17.2 Gopher Tortoise Control Through Trapping

Since the gopher tortoise is Federally listed as a threatened species, dam owners should contact the USFWS or their state wildlife agency for management guidance.

6.17.3 Gopher Tortoise Control Through Fumigants (University of Nebraska, 1994)

No fumigants are registered for gopher tortoise control.

6.17.4 Gopher Tortoise Control Through Toxicants (University of Nebraska, 1994)

No toxicants are registered for gopher tortoise control.

6.17.5 Gopher Tortoise Control Through Frightening

Frightening has not proven to be an effective method of gopher tortoise control and would be prohibited under the Endangered Species Act.

6.17.6 Gopher Tortoise Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for gopher tortoise control.

6.17.7 Gopher Tortoise Control Through Shooting (University of Nebraska, 1994)

Gopher tortoises are protected under the Endangered Species Act and therefore, cannot be shot. Dam owners should contact the USFWS or their state wildlife agency for management guidance.

6.18 Red Fox and Gray Fox Management Methods

6.18.1 Red Fox and Gray Fox Control Through Habitat Modification

Proper vegetative management (mowing and brush removal) and rodent control will often discourage foxes from digging in earthen dams by reducing their primary food source.

6.18.2 Red Fox and Gray Fox Control Through Trapping (University of Nebraska, 1994)

Trapping is a very effective method of controlling foxes, however it requires a great deal of expertise and training. Steel leg-hold traps (No. 1 ½, 1 ¾, and 2 doublespring coil traps; and No. 2 and 3 double longspring trap) are suitable for both red and gray foxes. Cage traps may be used for juvenile red foxes. Traps set along trails, at entrances to fields, and near bait carcasses are most effective.

Snares may also be used to capture foxes. Snaring involves setting a steel-cable loop in an animal's path to capture it by the neck, body, or leg. Snares should be made from 1/16-inch, 5/64-inch or 3/32-inch cable to capture red or gray foxes. The snare should have a 6-inch loop that is placed 10 to 12 inches off the ground. Snares should be set on trails or in crawl holes that are frequented by foxes.

Traps and snares are not legal in all states. Dam owners should contact their state wildlife agency for specific information on trapping regulations.

6.18.3 Red Fox and Gray Fox Control Through Fumigants (University of Nebraska, 1994)

Gas cartridges are the only registered fumigant for red and gray fox control. Gas cartridges are General Use Pesticides that can usually be purchased at local farm supply stores or pesticide dealers. When ignited and place in the den, a gas cartridge will produce carbon monoxide, carbon dioxide, and other gases that are toxic to the fox. Gas cartridges should be used with caution and in accordance with the directions on the label. Dam owners should consult with their state wildlife agency for information on state and local regulations regarding gas cartridges and the use of fumigants.

6.18.4 Red Fox and Gray Fox Control Through Toxicants (University of Nebraska, 1994)

The only toxicant registered for red and gray fox control is sodium cyanide used in an M-44 ejector device. The M-44 is a spring-activated device that expels a sodium cyanide capsule into the animal's mouth. It should be set along trails and at crossings regularly used by foxes. This is a Restricted Use Pesticide and may only be used by USDA Animal Damage Control personnel and, in some states, certified pesticide applicators. The M-44 is not registered in all states so dam owners must consult their state wildlife agency before implementing this control measure.

6.18.5 Red Fox and Gray Fox Control Through Frightening (University of Nebraska, 1994)

Noise-making devices such as radios, amplifiers, or propane exploders may temporarily deter foxes from inhabiting an area, but they do not provide a long-term solution.

6.18.6 Red Fox and Gray Fox Control Through Repellents (University of Nebraska, 1994)

No repellants are registered for red or gray fox control.

6.18.7 Red Fox and Gray Fox Control Through Shooting

Shooting is another method of managing both red and gray foxes. Hunting regulations and seasons vary by state. Dam owners should contact their state wildlife agency for specific information on hunting foxes.

6.19 Canada Goose Management Methods

6.19.1 Canada Goose Control Through Habitat Modification (Virginia Cooperative Extension, 2001b; University of Nebraska, 1994)

The following habitat modification techniques can be implemented to reduce Canada goose damage:

- Minimize the amount of forage plants that exists near the water body by mowing or hand removal.
- Construct a wire grid of stainless steel spring wire or monofilament line above the surface of the water. This will prevent Canada geese and other waterfowl from using the water and discourage them from nesting in that

area. The individual lines should be staked to the ground about 12 inches above the water's surface.

6.19.2 Canada Goose Control Through Trapping (University of Nebraska, 1994; Virginia Cooperative Extension, 2001b)

Live trapping may be effective for small populations of Canada geese. Several types of traps are effective including walk-in funnel traps, rocket or cannon nets, and spring-powered nets. A federal permit is required before trapping may be initiated. In addition, all relevant state and federal agencies must agree on what will happen to the geese after capture. Dam owners should contact the USFWS and their state wildlife agency for guidance.

Walk-in funnel traps are most effective in late June or early July. These types of traps can be constructed using poultry wire, woven wire fencing, steel fence posts, and netting (Figure 6-15). The trap should be set immediately next to the affected waterbody and then the geese should be herded into the trap. The herders must surround the geese on three sides, forcing them into the trap. Once the geese are secured in the trap, they may be transported to a designated location.

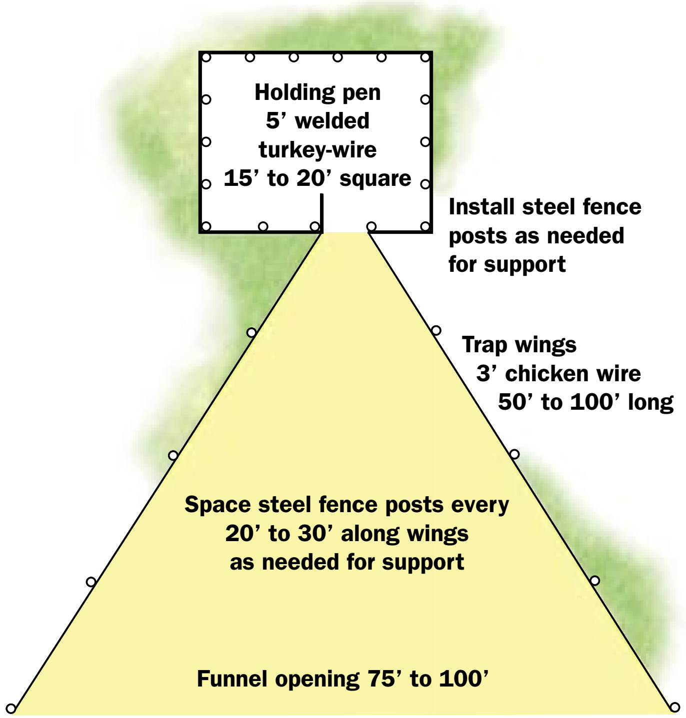


Figure 6-15. Canada goose funnel trap.

Net traps may also be used to capture Canada geese. Rocket or cannon nets with 2- to 2.5-inch mesh work well for large geese. The net should be placed at a location near the water and a second site should be repetitively baited with corn or other suitable bait until the bait is well accepted. Once the geese are trained to feed at the bait site, the area should be re-baited in preparation for capture. When the geese are concentrated at the site, the rocket or cannon net should be fired at the location so the birds are trapped underneath. The Canada geese can then be transported to a designated location. Spring-powered nets work in a similar fashion, though they are smaller than standard rocket or cannon nets. The net is triggered mechanically or electronically, and because it does not create as much noise as the rocket or cannon net, it may be more effective even though it is smaller.

A final method of capturing Canada geese is through the use of an immobilizing agent, Alpha-chloralose. Alpha-chloralose is a non-lethal chemical that is applied to bait and then fed to the geese. Approximately 20 to 90 minutes after ingestion, the geese will be unable to fly or escape and can be captured by hand. Alpha-chloralose may only be used by USDA Animal Damage Control (ADC) staff or biologists of other certified state or federal wildlife management agencies. Dam owners should contact USDA ADC staff, the USFWS, or their state wildlife agency for more information about this option

6.19.3 Canada Goose Control Through Fumigants

Fumigants are not a practical method of control for Canada geese.

6.19.4 Canada Goose Control Through Toxicants (University of Nebraska, 1994)

No toxicants are registered for Canada goose control.

6.19.5 Canada Goose Control Through Frightening (Virginia Cooperative Extension, 2001b)

Auditory and visual scare devices may be used to deter Canada geese from inhabiting an area. Auditory scare devices make loud noises that will frighten geese away. Commonly used devices include propane cannons, pyrotechnics, and pre-recorded tapes of Canada goose distress calls. Visual scare devices installed on or around an earthen dam are also effective. They are usually inexpensive and easy to install, but they work best in conjunction with another deterrent.

Examples of visual scare devices include strobe lights, scarecrows, owl effigies, mylar reflective tape, flags, and balloons.

Harassment or hazing of Canada geese is generally more effective than visual or auditory deterrents, but it can be labor intensive and expensive. Examples of common hazing programs include use of radio-controlled toys (boats or airplanes), trained dogs, or high-power water spray devices. These deterrent activities must be persistent and repeated to remain effective.

6.19.6 Canada Goose Control Through Repellents (Virginia Cooperative Extension, 2001b)

Methyl anthranilate has been registered as a goose repellant under the name ReJeX-iT. This repellant is non-toxic and does not harm the geese. Re-JeX-iT is applied directly to the grass of an affected area. It may have to be reapplied frequently to remain effective. Repellents should always be used as directed.

6.19.7 Canada Goose Control Through Shooting (University of Nebraska, 1994)

Hunting is another effective method of reducing Canada goose populations. Since Canada geese are listed as migratory birds under the Migratory Bird Treaty Act, a federal permit is required. In many areas, state permits are also required for hunting Canada geese. Dam owners should contact the USFWS and their state wildlife agency for specific hunting regulations and requirements.

6.19.8 Other Methods of Canada Goose Control

It is also possible to reduce resident Canada goose populations by oiling, shaking, or puncturing their eggs. This requires a federal permit; dam owners should contact USFWS and their state wildlife agency for more information.

6.20 American Alligator Management Methods

The American Alligator is Federally listed as a threatened species "due to similarity of appearance" to the federally endangered American crocodile. This listing grants the American Alligator protection under the Endangered Species Act. Dam owners who experience problems with nuisance alligators should contact the USFWS and their state wildlife agency for management guidance.

6.20.1 American Alligator Control Through Habitat Modification (University of Nebraska, 1994)

Removal of emergent wetland vegetation may reduce alligator densities by reducing cover. There are strict laws however, regarding human modifications to wetlands so dam owners must consult with appropriate state environmental agencies before disturbing any wetland vegetation.

6.20.2 American Alligator Control Through Trapping (University of Nebraska, 1994)

Trapping is an effective method of eliminating alligators from an area. A baited hook is the simplest and most effective method. This involves rigging a large fish hook (12/0 forged) with bait (e.g., fish, beef, chicken, or nutria) and suspending it via rope from a tree or pole about 2 feet above the water. When the alligator swallows the bait, the hook is lodged in its stomach and the alligator is retrieved using the attached rope. This method almost always kills or injures the alligator.

Trip-snare traps and wire box traps may also be used. They are not quite as effective as the baited hook, but they do not kill or injure the alligator, which then must be relocated. Dam owners must contact the USFWS and their state wildlife agency for information on trapping regulations, the Endangered Species Act, and permit requirements.

6.20.3 American Alligator Control Through Fumigants (University of Nebraska, 1994)

No fumigants are registered for alligator control.

6.20.4 American Alligator Control Through Toxicants (University of Nebraska, 1994)

No toxicants are registered for alligator control.

6.20.5 American Alligator Control Through Frightening (University of Nebraska, 1994)

Under the Endangered Species Act, no actions to harass or frighten a protected species are allowed.

6.20.6 American Alligator Control Through Repellents (University of Nebraska, 1994)

No repellents are registered for alligator control.

6.20.7 American Alligator Control Through Shooting (University of Nebraska, 1994)

Shooting is an effective method of eliminating alligators. A sufficiently powerful rifle (.243 caliber or larger) should be used for a humane kill. Dam owners must contact the USFWS and their state wildlife agency for information on hunting regulations, compliance with the Endangered Species Act, and permit requirements.

6.21 Ant Management Methods

6.21.1 Ant Control Through Habitat Modification (University of Georgia Cooperative Extension Service, 2000)

It may be possible to reduce ant populations by physically destroying visible ant mounds. This can be accomplished by simply knocking down or disturbing mounds with a stick or shovel. Another option is to pour very hot (almost boiling) water directly on each mound.

Pouring very hot water on each ant mound will eliminate about 60% of mounds.

6.21.2 Ant Control Through Trapping

Ant traps are commercially available, but they are not effective for large, outdoor ant infestations.

6.21.3 Ant Control Through Fumigants (University of Georgia, 1993; University of Georgia Cooperative Extension Service, 2000)

Fumigants may help control some type of ant species. Earthfire® (vaporized resmethrin) and Brom-O-Gas (methyl bromide) are two examples of fumigants that have proven effective against fire ants. Both are Restricted Use Pesticides that must be purchased and applied by a certified pesticide applicator. These fumigants may not necessarily be effective for all ant species. Dam owners should contact a professional pest removal company for information on fumigants that may be effective for their particular ant infestation.

6.21.4 Ant Control Through Toxicants (University of Florida Cooperative Extension Service, 2002)

Ants can usually be controlled with baits or chemical treatments. Many of these products are available commercially at hardware stores, home and garden suppliers, and other retail outlets. These treatments come in various forms, including granules, liquids, gels, and ready-to-use tamper resistant containers. Treatment should be tailored to the type of ant species present and the extent of infestation. Dam owners should contact their local cooperative extension agency or a professional pest control company for assistance. Professional pest control companies may also be able to provide stronger treatment options if damage is significant and the use of commercially available products is not effective.

Insecticides can contaminate both ground and surface waters so dam owners need to be particularly cautious when applying baits or chemical treatments near a reservoir. Insecticide use must occur in accordance with Federal law (FIFRA of 1996).

6.21.5 Ant Control Through Frightening

Frightening is not an effective or practical method of ant control.

6.21.6 Ant Control Through Repellents

Large, outdoor ant infestations cannot be effectively controlled through the use of repellents.

6.21.7 Ant Control Through Shooting

Shooting is not a practical method of ant control.

7.0 Fiscal Considerations for Managing Animal Damage on Earthen Dams

"There is no free lunch. Either we make the investments required to keep our nation's dams safe, or we will pay the price in dam failures."

Martin McCann, consulting professor of civil and environmental engineering at Stanford University and director of the National Performance of Dams Program (NPDP).

Almost everyone in the dam community agrees that the funds spent preserving a dam's integrity and safe operation will almost always be less than those spent repairing an unsafe dam or worse, recovering from a dam failure. The economics behind this understanding are self-explanatory and probably need no quantitative explanation; yet across the nation, dams deteriorate from animal intrusion damages and dam owners struggle with the financial responsibility of repairing their unsafe dams, or removing them altogether when the repair costs become too great. Clearly then, the economic considerations related to appropriate dam management go beyond the economic efficiency and long-term benefit of such repairs; the considerations involve acknowledgement of animal damages as a problem, human motivation factors, and the availability of funding mechanisms at the federal and state level.

7.1 Fiscal Considerations for the Reluctant Dam Owner

As indicated in the FEMA/ASDSO workshops, inspectors, engineers, and regulators can find it difficult to convince dam owners that animal burrows and erosion can have serious detrimental effects on their dams. Even though dam failures are becoming all too common—partially a product of America's aging dams—some dam owners put too much confidence in the integrity of their dams, even when visible evidence of animal burrows and inappropriate vegetation are present on their dams. For these dam owners, animal damage management is not likely to become a budget line item until an understanding is developed of how adverse animal intrusion effects can cascade, resulting in extensive repair/replacement costs, as well as the associated liabilities, that follow a dam failure.

7.2 Fiscal Considerations of the Willing Dam Owner

Other dam owners are aware of the dangers inherent to animal damages at an earthen dam, but overlook routine owner actions that are relatively affordable and can save hundreds of thousands of dollars in the long-term, not to mention reduce the public safety hazard for those located downstream of the dam. Inspections and repair actions are indeed overlooked, as documented by the states in the 2003 surveys and in the 2002 workshop where "financial limitations by owners" is listed as the most common impediment to timely and adequate dam upkeep. Considering that over 50% of the dams in this country are privately owned (AS-

DSO, 2003), financial limitations to upkeep pose a daunting threat to public safety.

Still other dam owners know the inherent problems of animal damage, and vigilantly conduct inspections, mow twice annually, and fill burrows in a timely manner. However, some dams because of their size, location, and biological attractiveness continue to have animal damage problems despite owner vigilance. In these cases, the dam owner pays continuously to correct animal damages and routine owner actions become an expensive proposition in terms of both time and money.

7.3 Overcoming the Economic Hurdles

The current and persisting economic issues with regard to animal damage management at earthen dams is twofold: first, reluctant owners need to be educated on the dangers of animal damages and motivated by economic examples; and second, funding sources for all owners need to be identified to assist funding of needed repairs. To begin to address the first consideration, a simple estimate of routine dam maintenance as it relates to vegetation and animal management (one influences the other) is given below:

Table 7.1

Vegetation Management (mowing twice per year)	$500 to $1000 annually*
Owner Inspection (one to two times per year)	No cost for dam owner inspection; inspection once every 2 to 5 years by a Professional Engineer can cost between $3,500 and $7,500
Filling animal burrows (per burrow)	$100 to $300 depending upon burrow size and repair method (grout or excavate and replace)

*for most dams, as indicated in FEMA, 2002.
This estimate assumes the dam is in good condition and that the owner is providing upkeep of an already stable operation

As the table indicates, the cost of routinely maintaining a dam is estimated at greater than $500.00 dollars per year. For many private dam owners, such as businesses and citizens, the outlay of these funds, though relatively low, is prohibitive. Even those dam owners with substantial financial resources are often overwhelmed by the costs of dam maintenance and repairs (WaterWebster, 2003). In these cases, it is important for dam owners to consider that neglect will eventually lead to greater costs on many levels; in short, dam owners can't afford to save money when it comes to the upkeep of their dams. Economic impacts of a failed dam can include:

Liability Costs of Loss of Life and Property Damage. Liability may be imposed on a dam owner if maintenance, repair, or operations were conducted in an unsafe or improper manner. Liability could apply to the dam owner as well as the company who possesses the dam and the individual who or company which operates and maintains the dam. The dam owner must take actions to ensure the dam functions properly so that injuries to people or property are avoided. This applies to foreseeable conditions or circumstances that can be predicted with reasonable certainty. If an inspection identifies problems at the dam, then an owner should correct them (Pennsylvania DEP, 1995).

Clean-up Costs. The costs associated with clean-up from a dam failure can be tremendous, depending on the size of the reservoir and the amount of downstream development. Debris removal, sediment clean-up, and reconstruction of damaged infrastructure could be required.

Loss of Dam Infrastructure and Its Revenue. Over 30% of the dams in the United States are used primarily for recreation (ASDSO, 2003). The benefit of dams to recreational income to the community can be in the millions of dollars each year, depending on the reservoir size and recreational opportunities available.

Environmental Losses. Many reservoirs provide wildlife habitat and associated ecotourism revenue, which generates $59 billion annually in the United States. Communities often benefit from the "wilderness" which dams and their reservoirs provide.

Economic Effect on Community. A community that depends on the dam for several uses (e.g., flood control, irrigation, water supply) will have to locate other facilities to serve these purposes should the dam fail or be removed. Alternative sources could be costly or may not be available as quickly as needed, resulting in an adverse social and economic impact on the community.

In essence, a neglected dam can cause a cascade of adverse effects at the community level as well as result in liability issues for the dam owner. Attaching a reasonable dollar figure to each of the considerations above would illustrate that this considerable investment per year in maintenance is like paying an insurance premium that covers the dam owner and their community.

Lessons Learned:

- Maintenance of animal burrows is critical. Burrows should be backfilled and animals removed as soon as possible.
- Owners should inspect their dams in a regular and thorough manner.
- Pond levels should be monitored and safety precautions such as spillways and freeboard should be factored into design.

The second consideration presents the most current and widespread dilemma facing the entire dam community. Many dam owners conduct inspections and typical maintenance as required, but preventive measures and wildlife mitigation actions may also be required. It would seem that vigilant dam owners would ensure the required actions were forthcoming; however, this is not always the case. According to the workshop (FEMA, 2001) and the state surveys (FEMA, 2003), and as echoed in the document The Cost of Rehabilitating Our Nation's Dams (ASDSO, 2003), owners of dams in need of repair are often not able to finance the required actions due largely to a lack of funding mechanisms at the state and federal levels; dams become neglected and deteriorate to the point of being hazardous. Currently, there are only a handful of states that provide financial assistance in the form of loans or grants to repair unsafe dams, as presented in Table 7-2.

Animal Burrows Contribute to $5 Million Dam Breach

Wallula, Iowa

The Iowa Beef Processor's (IBP) Waste Pond was constructed in 1971 to store wastewater from the IBP Plant. When full, the pond had a surface area of 37 acres and a maximum storage capacity of 270 acre-feet. The pond was located on a natural drainage course and was impounded behind a 15-foot-high, 1000-foot-long earthen dam. State inspections in 1981 and 1985 discovered that the embankment was riddled with animal burrows. It was recommended that the burrows be filled and the animals removed from the site. Repairs were not made quickly enough, and the rapid melting of record snow pack coupled with higher than normal pond levels filled the waste pond and overtopped a portion of the west end of the dam (the dam had no emergency spillway). High pond levels allowed water to exit through animal burrows that were normally above the pond elevation. Uncontrolled leakage and seepage through the animal borrows exiting on the downstream face likely resulted in erosion that backcut rapidly toward the upstream face, eventually breaching the dam.

The estimated cost of the failure was $5 million, which included the cost of the five locomotives that were derailed downstream, environmental cleanup, and repair to the rail line. The cost to construct a new facility was several million more dollars.

Table 7-2 Summary of State Dam Funding Programs

State	Program Name and Type	Eligibility	Loan/Grant Amount
Arizona	Dam Repair (loan or grant)	State engineer determines dam to be dangerous to life, non-emergency	Loan – Cost of project
Maryland	Maryland Environmental Service (loan and planning assistance)	Counties, utilities, and private groups; must have established service district for water supply, resource reclamation, dredging or stormwater	
Massachusetts	No name given (grants)	Local communities for repair or removal	75% of the project; local share can be in-kind contributions
New Jersey	Dam Restoration and Clean Water Trust Fund (revolving loan fund; new grant fund for municipally-owned dams)	Local units of governments; private owners can be co-applicants	Loan – Cost of project Grants – Up to 100%
New York	Clean Water/Clean Air Bond Act (grants)	Municipalities for dam safety projects	75% of eligible project with 25% local match; $300,000 cap per project
Ohio	Ohio Water Development Authority (revolving loan fund)	Owner must be under mandate from ODNR **Dam Safety Loan Program** – Local units of government, state, districts **Dam Safety Linked Deposit Program** – private owners/organizations	Cost of project
Pennsylvania	Pennvest (revolving loan fund)	Projects associated with wastewater, water supply, or stormwater	Up to cost of project
Utah	Utah Board of Water Resources (loans or grants)	High hazard dam owners; mandated repairs	80-95% grant for irrigation or water supply dams; loans or grants for other owners
Wisconsin	DNR Municipal Dam Grant Program (grants)	Local units of government and lake districts	50-50 grants; $200,000 maximum

Similarly, the federal government extends dam rehabilitation assistance through only a few programs. The combination of existing state and federal assistance does not approach the estimated $36.2 billion needed nationwide to support needed dam repair and rehabilitation related to wildlife damages and other structural integrity issues.

Table 7-3. Summary of Potential Federal Programs for Dam Management

Agency	Program	Description
Natural Resources Conservation Service, Department of Agriculture	10.916 Watershed Rehabilitation Program	Provides grants to rehabilitate dams originally built with assistance from USDA Watershed Programs. Rehabilitation must extend the life of the dam and meet applicable performance and safety requirements. Priority is given to high hazard dams.
Natural Resources Conservation Service, Department of Agriculture	10.904 Watershed Protection and Flood Prevention	Provides grants and technical assistance to carry out watershed improvement projects that protect, develop, and utilize the land and water resources in small watersheds.
Bureau of Indian Affairs, Department of the Interior	15.065 Safety of Dams on Indian Lands	Provides direct payments to federally recognized Indian tribal governments and Native American organization to improve the structural integrity of dams on Indian lands.
Federal Emergency Management Agency, Department of Homeland Security	97.047 Pre-Disaster Mitigation (PDM)	Provides grants to states and communities for cost-effective hazard mitigation activities that are part of a comprehensive mitigation program, and that reduce injuries, loss of life, and damage and destruction of property. Dam repair and rehabilitation projects may be eligible for PDM funding if: • The project has a high benefit-cost ratio; • There is a high risk of dam failure or dam failure would result in significant damages; and • The project is consistent with State funding priorities.
Federal Emergency Management Agency, Department of Homeland Security	P.L. 107-310 National Dam Safety and Security Act of 2002	Funds are granted each year to state dam safety programs.
Federal Insurance and Mitigation Administration, Federal Emergency Management Agency	83.550 National Dam Safety Program (Dam Safety State Assistance Program)	Funds are distributed each year (in the form of project grants) to state dam safety programs.

In conclusion, the dam community is composed of owners in need of education and economic understanding of the consequences associated with neglected dams, as well as those owners who are diligent in dam upkeep, but perhaps unable to fund the necessary repair and preventive actions. Even if federal, state, and local agencies can educate the reluctant dam owners such that they become vigilant in the upkeep of their dams, our nation's dams will likely continue to degrade without adequate funding to implement the sometimes perpetual animal damage repair and management needed.

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Appendix A
State Wildlife Agency Contacts

Alabama Department of Conservation and Natural Resources
Division of Wildlife and Freshwater Fisheries
64 N. Union Street
Montgomery, Alabama 36130
(334) 242-3469

Alaska Department of Fish and Game
PO Box 25526
Juneau, Alaska 99802-5526
(907) 465-4100

Arizona Game and Fish Department
2221 W. Greenway Road
Phoenix, Arizona 85023-4399
(602) 942-3000

Arkansas Game and Fish Commission
Natural Resources Drive
Little Rock, Arkansas 72205
(501) 223-6359

California Department of Fish and Game
1416 Ninth Street
Sacramento, California 95814
(916) 445-0411

Colorado Department of Natural Resources
Division of Wildlife
6060 Broadway
Denver, Colorado 80216
(303) 297-1192

Connecticut Department of Environmental Protection
Bureau of Natural Resources, Wildlife Division
79 Elm Street
Hartford, Connecticut 06106-5127
(860) 424-3011

Delaware Department of Natural Resources and
Environmental Control
Division of Fish and Wildlife
89 Kings Highway
Dover, Delaware 19901
(302) 739-5297

Florida Fish and Wildlife Conservation Commission
620 South Meridian Street
Tallahassee, Florida 32399-1600
(850) 921-5990

Georgia Department of Natural Resources
Wildlife Resources Division
2070 U.S. Highway 278, S.E.
Social Circle, Georgia 30025
(770) 918-6400

Hawaii Department of Land and Natural Resources
Division of Forestry and Wildlife
1151 Punchbowl Street, Room 325
Honolulu, Hawaii 96813
(808) 587-0166

Idaho Department of Fish and Game
600 S. Walnut, PO Box 25
Boise, Idaho 83707
(208) 334-3700

Illinois Department of Natural Resources
1 Natural Resources Way
Springfield, Illinois 62702-1271
(217) 782-6302

Indiana Department of Natural Resources
Division of Fish and Wildlife
402 W. Washington Street, Room W273
Indianapolis, Indiana 46204
(317) 232-4080

Iowa Department of Natural Resources
Wildlife Bureau
Henry A. Wallace Building
502 E. 9th Street
Des Moines, Iowa 50319-0034
(515) 281-5918

Kansas Department of Wildlife and Parks
14639 W. 95th
Lenexa, Kansas 66215
(913) 894-9113

Kentucky Department of Fish and Wildlife
1 Game Farm Road
Frankfort, Kentucky 40601
(800) 858-1549

Louisiana Department of Wildlife and Fisheries
2000 Quail Drive
Baton Rouge, Louisiana.70808
(225) 763-3557

Maine Department of Inland Fisheries and Wildlife
284 State Street
41 State House Station
Augusta, Maine 04333-0041
(207) 287-8000

Maryland Department of Natural Resources
Wildlife and Heritage Service
Tawes State Office Building, E-1
580 Taylor Avenue
Annapolis, Maryland 21401
(410) 260-8540

Massachusetts Department of Fisheries, Wildlife and
Environmental Law Enforcement
Division of Fisheries & Wildlife
251 Causeway Street, Suite 400
Boston, Massachusetts 02114-2152
(617) 626-1590

Michigan Department of Natural Resources
Wildlife Division
Mason Building, Fourth Floor
PO Box 30444
Lansing, Michigan 48909-7944
(517) 373-1263

Minnesota Department of Natural Resources
500 Lafayette Road
St. Paul, Minnesota 55155-4040
(651) 296-6157

Mississippi Department of Wildlife, Fisheries and Parks
1505 Eastover Drive
Jackson, Mississippi 39211-6374
(601) 432-2400

Missouri Department of Conservation
2901 W. Truman Boulevard
Jefferson City, Missouri 65109
(573) 751-4115

Montana Fish, Wildlife & Parks
1420 East Sixth Avenue
Helena, Montana 59620-0701
(406) 444-2535

Nebraska Game and Parks Commission
2200 North 33rd Street
Lincoln, Nebraska 68503
(402) 471-0641

Nevada Department of Wildlife
1100 Valley Road
Reno, Nevada 89512
(775) 688-1500

New Hampshire Fish and Game Department
Wildlife Division
11 Hazen Drive
Concord, New Hampshire 03301
(603) 271-2461

New Jersey Department of Environmental Protection
Division of Fish and Wildlife
PO Box 400
Trenton, New Jersey 08625-0400
(609) 292-2965

New Mexico Department of Game and Fish
PO Box 25112
Santa Fe, New Mexico 87507
(800) 862-9310

New York State Department of Environmental Conservation
Division of Fish, Wildlife and Marine Resources
625 Broadway
Albany, New York 12233-4750
(518) 402-8919

North Carolina Wildlife Resources Commission
Archdale Building
512 N. Salisbury Street
Raleigh, North Carolina 27604-1188
(919) 733-7191

North Dakota Game and Fish Department
100 N. Bismarck Expressway
Bismarck, North Dakota 58501-5095
(701) 328-6300

Ohio Department of Natural Resources
Division of Wildlife
1840 Belcher Drive
Columbus, Ohio 43224-1300
(800) 945-3543

Oklahoma Department of Wildlife Conservation
1801 N. Lincoln
Oklahoma City, Oklahoma 73105
(405) 521-3851

Oregon Department of Fish and Wildlife
3406 Cherry Avenue N.E.
Salem, Oregon 97303-4924
(503) 947-6000

Pennsylvania Game Commission
2001 Elmerton Avenue
Harrisburg, Pennsylvania 17110-9797
(717) 787-4250

Rhode Island Department of Environmental Management
Division of Fish and Wildlife
4808 Tower Hill Road
Wakefield, Rhode Island 02879
(401) 789-3094

South Carolina Department of Natural Resources
Wildlife and Freshwater Fisheries Division
PO Box 167
Columbia, South Carolina 29202
(803) 734-3886

South Dakota Department of Game, Fish, and Parks
Wildlife Division
523 East Capitol Avenue
Pierre, South Dakota 57501-3182
(605) 773-3381

Tennessee Wildlife Resources Agency
Wildlife Division
Ellington Agricultural Center
PO Box 40747
Nashville, Tennessee 37204
(615) 781-6610

Texas Parks and Wildlife Department
4200 Smith School Road
Austin, Texas 78744
(800) 792-1112

Utah Department of Natural Resources
Division of Wildlife Resources
1594 W. North Temple
Salt Lake City, Utah 84114
(801) 538-4700

Vermont Agency of Natural Resources
Fish and Wildlife Department
103 South Main Street
Waterbury, Vermont 05671-0501
(802) 241-3700

Virginia Department of Game and Inland Fisheries
4010 West Broad Street
Richmond, Virginia 23230
(804) 367-1000

Washington Department of Fish and Wildlife
Natural Resources Building
1111 Washington Street, SE
Olympia, Washington 98501
(360) 902-2200

West Virginia Division of Natural Resources
Wildlife Resources
State Capitol Building 3, Room 812
Charleston, West Virginia 25305
(304) 558-2771
Wisconsin Department of Natural Resources
101 South Webster Street
Madison, Wisconsin 53703
(608) 266-2621

Wyoming Game and Fish Department
5400 Bishop Boulevard
Cheyenne, Wyoming 82006-0001
(307) 777-4600

Appendix B
Association of State Dam Safety Officials Contact Information

Association of State Dam Safety Officials
450 Old Vine Street, 2nd Floor
Lexington, KY 40507-1544
Phone: 859-257-5140
Fax: 859-323-1958
E-Mail: info@damsafety.org
Web: www.damsafety.org

Lori Spragens, Executive Director lspragens@damsafety.org

Susan Sorrell, Meetings & Membership Director
sasorrell@damsafety.org

Sarah Mayfield, Information Specialist smayfield@damsafety.
org

Maureen Hogle, Administrative Database Specialist
mhogle@damsafety.org

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Technical Manual for Dam Owners

Impacts of Plants on Earthen Dams

FEMA 534 / September 2005

FEMA

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PREFACE

Damage to earthen dams and dam safety issues associated with tree and woody vegetation penetrations of earthen dams is all too often believed to be a routine maintenance situation by many dam owners, dam safety regulators, and engineers. Contrary to this belief, tree and woody vegetation penetrations of earthen dams and their appurtenances have been demonstrated to be causes of serious structural deterioration and distress that can result in failure of earthen dams. For the first time in the history of dam safety, a Research Needs Workshop on Plant and Animal Impacts on Earthen Dams (Workshop) was convened through the joint efforts of the Federal Emergency Management Agency (FEMA) and the Association of State Dam Safety Officials (ASDSO) in November 1999 to bring together technical resources of dam owners, engineers, state and federal regulators, wildlife managers, foresters, and members of academia with expertise in these areas. The Workshop highlighted the realization that damage to earthen dams resulting from plant and animal penetrations was indeed a significant dam safety issue in the United States. The purpose of this *Technical Manual for Dam Owners, Impacts of Plants on Earthen Dams* is to convey technology assembled through the Workshop by successful completion of four objectives. These objectives are as follows:

1. Advance awareness of the characteristics and seriousness of dam safety problems associated with tree and woody vegetation growth impacts on earthen dams;

2. Provide a higher level of understanding of dam safety issues associated with tree and woody vegetation growth impacts on earthen dams by reviewing current damage control policies;

3. Provide state-of-practice guidance for remediation design considerations associated with damages associated with tree and woody vegetation growth on earthen dams; and

4. Provide rationale and state-of-practice techniques and procedures for management of desirable and undesirable vegetation on earthen dams.

ACKNOWLEDGEMENTS

The editors of this *Technical Manual for Dam Owners, Impacts of Plants on Earthen Dams* wish to acknowledge the support of the dam safety organizations and agencies and many dedicated individuals that made significant contributions to the contents of this Manual.

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The Steering Committee of the Workshop was comprised of the following individuals who contributed significantly and diligently to making the Workshop a truly historical dam safety technological event:

Dr. B. Dan Marks, P.E. (Chairman)
Dr. Bruce A. Tschantz, UT Knoxville
David K. Woodward, NCSU
Charles Clevenger, MS (Deceased)
William L. Bouley, USBR
Sarah M. Mayfield, ASDSO
Susan A. Sorrell, ASDSO (Project Coordinator)

Participants in the Workshop brought together diverse technologies, experiences, and scientific developments to create a significant contribution to dam safety in the United States. The editors of this Manual acknowledge the valuable contributions of the following Workshop participants:

Matthew A. Barner, Wright State Univ.	**Douglas E. McClelland, USDA Forest Service**
William L. Bouley, USBR	**Dr. James E. Miller, USDA-CSREES/NRE**
Charles Clevenger, MS (Deceased)	**Dr. Dale L. Nolte, USDA-APHIS/WS/NWRC**
Dr. Kim D. Coder, Univ. of Georgia	**Richard D. Owens, USDA-APHIS/WS**
Gary Drake, Reemay, Inc.	**Tom Renckly, Maricopa County, AZ**
Edward Fiegle, GA Dam Safety	**Dr. David Sisneros, USBR**
James K. Leumas, NC Dam Safety	**Boris Slogar, OH Dam Safety**
Dr. B. Dan Marks, Marks Enterprises	**Susan A. Sorrell, ASDSO**
Sarah M. Mayfield, ASDSO	**Dr. Bruce A Tschantz, UT Knoxville**
Dr. Marty McCann, NPDP-Stanford	**David K. Woodward, NCSU**

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Timothy G. Schaal, SD Water Rights Program	**Daniel M. Hill, Burgess & Niple, Ltd.**
R. David Clark, MA Office of Dam Safety	**James K. Leumas, City of Raleigh, NC**

Lori Spragens, ASDSO Executive Director (Project Coordinator)

Because of the efforts of the many individuals previously mentioned, the editors are confident that users of this Manual will develop a better understanding and gain a greater appreciation of the seriousness and magnitude of problems associated with the effects of tree and woody vegetation root penetrations on the safety of earthen dams and their appurtenances.

GLOSSARY

This glossary provides the definitions of some of the basic terms used in this ***Manual*** and is not intended to be a comprehensive glossary of terms associated with dam safety. A more extensive resource of dam safety terms and definitions is available through the many references provided at the end of each chapter of the ***Manual***.

Absorption - the process of being taken into a mass or body, as water being taken in by plant roots.

Abutments - the interface between the sides of a valley containing a dam and the dam embankment. Right and left abutments are referenced by viewing the dam while facing downstream.

Adsorption – the adhesion of an extremely thin layer of molecules to the surface of solid bodies or liquids with which they are in contact.

Appurtenances – structures associated with dams such as spillways, gates, outlet works, ramps, docks, etc. that are built to allow proper operation of dams.

Berm – a horizontal step or bench in the embankment slope of an earthen dam.

Biological Barrier – an herbicidal releasing system, device, or material designed to exclude root growth and/or penetration of plants into a protected underground zone (such as a dam embankment).

Boil – a typically circular feature created by the upward movement of soil particles by seepage flowing under a pressure slightly greater than the submerged unit weight of the soil through which seepage is occurring.

Breach – a break, gap, or opening in a dam that typically allows uncontrolled release of impounded water.

Capillary Rise – the rise of water in the voids of a soil mass as a result of the surface tension forces of water.

Clearing – the removal of trees and woody vegetation by cutting without removal of stumps, rootballs, and root systems.

Crest – the near horizontal top surface of an earthen dam, or the control elevation of a spillway system.

Diameter at Breast Height (dbh) – the diameter of a tree measured at about four feet (breast height of average person) above the ground surface.

Drainage System – graded and/or protected pervious aggregates in a dam designed to collect, filter, and discharge seepage through the embankment, abutments, or foundation.

Earthen Dam – a dam constructed of compacted natural soil fill materials selected to minimize embankment seepage while maximizing workability and performance.

Embankment – an earthen or rockfilled structure having sloping sides constructed of select compacted fill materials.

Failure – a (dam) incident that results in the uncontrolled release of water from the impoundment of a dam.

Freeboard – the vertical distance from the normal operating water level of an impoundment to the crest (top) of the dam.

Grubbing – the removal of stumps, rootballs, and lateral root system of trees and woody vegetation. A construction operation that is typically done following the clearing operation.

Herbicide – a chemical substance or mixture designed to kill or maintain undesirable Plants that may include herbaceous plants, vines, brush, and trees.

Hydraulic Height (of a Dam) – the vertical distance from the normal operating water level of the impoundment to the invert of the outlet works or downstream outlet channel.

Hydro-seeding – the technique of applying grass seeds, fertilizer, agricultural lime, and seedbed mulch to seeded area in a pressurized aqueous mixture.

Lateral Root System – roots of trees and woody plants that extend laterally from the tap root and/or rootball to provide lateral support and nutrient uptake for the plant.

Line of Saturation – the leading boundary of the progression of saturation of soil in an embankment exposed to an increasing head (source) of water (impoundment).

Line of Wetting – the leading boundary of the progression of wetting (partial saturation) of soil in an embankment exposed to an increasing head (source) of water (impoundment).

Maintenance – routine upkeep necessary for efficient inspection, and safe operation and performance of dam and their appurtenances. Labor and materials are required; however, maintenance should never be considered to comprise dam remediation.

Mowing – the cutting of grass, weeds, and small-diameter woody vegetation by mechanical devices such as mowers, bush hogs, and other vegetation cutting machinery.

Mulching – the application of protective material such as straw, fiber matting, and shredded paper to newly seeded areas.

Operation (of a dam) – activity by a dam owner for the necessary and safe use and performance of a dam, the appurtenances of a dam, and the impoundment.

Owner – any person or organization that owns, leases, controls, operates, maintains, or manages a dam and/or impoundment.

Phreatic Surface – the upper boundary (surface) of seepage (water flow) zone in an embankment.

Piping – the progressive downstream to upstream development of internal erosion of soil as a result of excessive seepage that is typically observed downstream as a hole, or boil, that discharges water containing soil particles.

Remediation – restoration of a dam to a safe and intended design condition.

Revegetation – restoration of desirable ground cover vegetation (i.e. grasses) to disturbed areas designed to prevent embankment surface erosion.

Rootball – the root and soil mass portion of a tree or woody plant that is located directly beneath the trunk or body of the tree that provides the primary vertical support for the tree or woody plant.

Root Penetration – intrusion of plant roots into a dam embankment so as to interfere with the safe hydraulic or structural operation of the dam.

Root System – roots contained in the rootball and the lateral root system collectively comprise the root system of trees and woody plans and provide both lateral and vertical support for the plant as well as providing water and nutrient uptake for the plant.

Seeding – application of a seeding mixture to a prepared seedbed or disturbed area.

Seepage – the flow of water from an impoundment through the embankment, abutments, or foundation of a dam.

Seepage Line – the uppermost boundary of a flow net, or the upper surface (boundary) of water flow through an embankment (see Phreatic Surface).

Slump – a portion of soil mass on an earthen dam that has or is moved downslope, sometimes suddenly, often characterized by a head scarp and tension cracks on the crest and embankment slope.

Spillway Systems – control structures over or through which flows are discharged from the impoundment. Spillway systems include Primary or Principal Spillways through which normal flows and small storm water flows are discharged and Auxiliary or Emergency Spillways through which storm water flows (floods) are discharged.

Stripping – the removal of topsoil, organic laden materials, and shallow root systems by excavating the ground surface (surficial soil stratum) after grubbing an area.

Structural Height (of a Dam) – the vertical distance from the crest (top) of the dam to the lowest point at the toe of the downstream embankment slope, or downstream toe outlet channel.

Stump – that portion of the trunk or body of a tree or woody plant left after removal by cutting during timber harvesting and/or clearing of trees and woody plants.

Stump Diameter – the diameter of a tree or woody plant at the ground surface.

Tap Root – the primary vertical root in the rootball that is the origin of development for the rootball and lateral root system growth.

Toe of Embankment – the point of intersection of the embankment slope of a dam with the natural ground surface.

Weeds – shallow-rooted, non-woody plants that grow sufficiently high as to hinder dam safety inspections and do not provide desirable embankment slope protection against surface runoff.

Woody Vegetation – plants that develop woody trunks, rootballs, and root systems that are not as large as trees but cause undesirable root penetration in dams.

Zone of Aeration – the partially saturated zone of a soil mass above the zone of saturation (above the height of capillary rise of water in a soil mass).

Zone of Saturation – the saturated zone of a soil mass above the phreatic surface defined by the height of capillary rise.

Chapter 1
Introduction

At the time Joyce Kilmer dedicated his famous poem "**Trees**" to Mrs. Henry Mills Alden, he was undoubtedly inspired by the beauty of a healthy living tree, and rightly so. For those that do not remember, the first verse of this famous poem is as follows: "***I think that I shall never see / A poem lovely as a tree.***" Most people are inspired and impressed by the splendor of trees; however, dam owners, operators, inspectors, dam safety regulators, engineers, and consultants might find the following verse more nearly appropriate. "***I think that I shall never see / A sight so wonderful as a tree / Removed from an earthen dam / Whose future safety we wish to see.***" This paraphrased verse is not intended to debase the great works of Joyce Kilmer; but rather, is intended to draw attention to the fact that trees and woody vegetation growth have no place on the embankment of an earthen dam.

Dam safety regulators and inspectors, engineers, and consultants are frequently confronted with grass roots resistance in the issue of removal of trees and woody vegetation from earthen dams. This resistance is often associated with sentimental, cultural, ecological, legal, and financial issues. A fundamental understanding and technical knowledge of potential detrimental impacts of trees and woody vegetation growth on the safety of earthen dams is necessary in order to address these issues.

Purpose

The purpose of this ***Manual*** is to provide the dam owner, operator, inspector, dam safety regulator, engineer, and consultant with the fundamental understanding and technical knowledge associated with the potential detrimental impacts of tree and woody vegetation growth on the safety of earthen dams. In addition to objectives related to raising the knowledge level of detrimental effects of trees and woody vegetation growth on the safety of earthen dams, the contents will provide the user of this ***Manual*** with an understanding of the methods, procedures, and benefits of maintaining a growth of desirable ground covering vegetation on the embankments of earthen dams.

Scope

The editors of this ***Manual*** have organized the contents in a sequential manner in order that the reader and user of this ***Manual*** can develop the desired fundamental understanding and gain the technical knowledge associated with the detrimental impacts of tree and woody vegetation growth on earthen dams. Chapter 2 deals with the problems associated with tree and woody vegetation growth on earthen dams. Chapter 3 presents some common misconceptions about tree growth and tree root development. These misconceptions are contrasted with factual data about tree growth and tree root development.

Chapter 4 presents a recommended earthen dam inspection protocol and procedures for determination of potential impacts of tree and woody vegetation growth on earthen dams. Chapter 5 begins the presentation of proper vegetation management on earthen dams. The user of this ***Manual*** is presented with methods and procedures for maintaining desirable vegetation growth, while also controlling tree and woody vegetation growth.

Chapter 6 presents a number of remediation design considerations associated with the removal of trees and woody vegetation from the embankments of earthen dams. This chapter also presents a recommended phased-remediation procedure for removal of undesirable vegetation (trees and woody vegetation) from earthen dam embankments. Chapter 7 is a succinct factual presentation of costs associated with either continual proper vegetative maintenance or long-term dam remediation construction after tree and woody vegetation removal. The contents of this chapter should make every dam owner cognizant of the need for proper operation and maintenance relative to vegetative growth on earthen dams.

Implementation

While this ***Manual*** may not be considered highly technical relative to the presentation of complex engineering calculations for the solution of potentially serious earthen dam safety problems, this ***Manual*** does present a combined sixty-five years of research and practice in dam safety engineering associated with tree and woody vegetation growth impacts on earthen dams. This ***Manual*** is presented in a manner to be beneficial to the entire dam safety community (dam owners, dam operators, dam safety inspectors, dam safety regulators, dam safety engineers and consultants). Dam safety engineers and consultants can utilize this ***Manual*** as a reference for recommendations for proper maintenance of desirable vegetation growth, control of undesirable vegetation growth, and remediation dam design associated with the removal and control of trees and woody vegetation growth on earthen dams. Dam safety regulators and dam safety inspectors can utilize this ***Manual*** as a guideline for the inspection of earthen dams relative to tree and vegetation growth dam safety issues and for the direction of dam owners and operators in the proper method and procedures for maintaining earthen dams without detrimental vegetative growth. Dam owners and operators can utilize this ***Manual*** to establish proper operation and maintenance programs to promote the growth of desirable vegetative growth on earthen dams and/or remove and control the undesirable tree and woody vegetation growth on earthen dams.

The last verse in the famous poem **Trees** by Joyce Kilmer is as follows: **"Poems are made by fools like me / But only God can make a tree."** Again, the author will paraphrase this last verse, not to debase the great works of Joyce Kilmer, but to make a distinct point. **"Only God can make a tree / But not removing trees from dams / Is done by fools like me."**

There is yet much research and study to be done relative to the growth of proper vegetative cover on earthen dams. However, there is no doubt that trees and woody vegetation have no place on the embankment slopes of an earthen dam. The authors of this ***Manual*** intend to continue technological development in the area of controlling tree and woody vegetation growth on earthen dams. The authors would appreciate documentation of unusual cases of tree and woody vegetation growth related to safety issues associated with earthen dams. Documentation of these issues can be communicated through ASDSO and/or directly to the authors of this ***Manual***.

Chapter 2
Problems with Tree and Woody Vegetation Growth

According to the 1998-99 National Inventory of Dams (NID) data, there are approximately 76,700 dams of significant size[1] and hazard category in the 50 states (USCOE, 1999). Most of these dams are regulated by the jurisdictional states, but many are not because of specific exemption clauses or different size or hazard restrictions. Because some states have lower size definitions for their dams than used for the NID count, the actual number of state-regulated dams is much higher (about 94,000). In Tennessee over 40 percent of the approximately 1000 inventoried dams ***not*** subject to regulation because of statutorily named county exclusions or agricultural use exemptions. Most of these unregulated dams and some of the regulated dams in Tennessee have troublesome trees and brush growing on their faces and crests. Some states estimate that as many as 95 percent of their regulated dams have trees. Figure 1 illustrates the general magnitude and range of the tree growth on regulated dams in 48 states where this information is reported (ASDSO, 2000). About half of the state-regulated dams are estimated to have excessive tree growth.

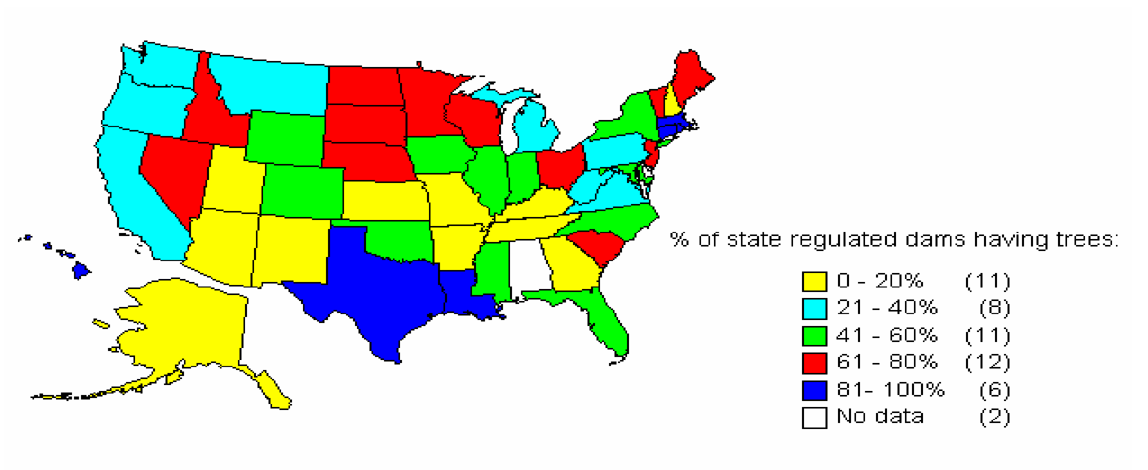

Figure 1. Estimated percentages of state-regulated dams having trees.

[1] Inclusion in the National Inventory has been defined under P.L. 99-662 and P.L. 92-367 to include dams that are at least 25 ft. high or 50 acre-feet of storage (excluding low hazard dams less than 6 ft. high or 15 acre feet of storage) and dams that due to location may pose a significant threat to human life or property in event of failure.

Most dam safety engineers, including state and federal officials, consultants, and other experts involved with dam safety, agree that when trees and woody plants are allowed to grow on earthen dams, they can hinder safety inspections, can interfere with safe operation, or can even cause dam failure. In the past, engineers and dam safety experts have not always been in agreement about the best way to prevent or control tree growth, remove trees, or repair safety-related damages caused by trees and woody vegetation. However, all dam engineers agree that a healthy, dense stand of low-growing grass on earthen dams is a desirable condition and should be encouraged.

From November 30 - December 2, 1999, a joint ASDSO/FEMA-sponsored workshop was held in Knoxville, Tennessee, for the purpose of inviting a panel of experts to discuss various problems, policies, and practices associated with plant and animal penetrations of earthen dams. Much of this manual follows up the work and recommendations produced by the workshop participants for engineers and owners to use in managing problems associated with both plant and animal intrusions. This chapter will discuss the consensus of current attitudes, issues, and policies involving woody vegetation penetrations of earthen dams, by state and federal officials, researchers, and practitioners active in dam safety.

Attitudes Toward Woody Plant Growth on Dams

The Association of State Dam Safety Officials (ASDSO) sent out survey questionnaires to dam safety officials in all 50 states and to federal representatives to the Interagency Committee on Dam Safety (ICODS) to determine state and federal agency attitudes about the effects of trees and woody plant growth on dams under their jurisdiction (ASDSO, 1999).

In this survey the state and federal agency representatives were asked (1) if they considered vegetative growth to be a problem on dams, (2) if they had specific policies or operating procedures for removing unwanted vegetation and trees on dams and if they didn't, how did they handle such problems, (3) what legal, financial, environmental or other constraints did they have in dealing with unwanted vegetation problems, (4) to provide documented evidence and examples where vegetation has negatively affected the safe operation or has contributed to the failure of dams, (5) to provide references to current or past research regarding the effects of plants and trees on dam safety, and (6) to provide example cost and other information related to rehabilitation and remediation of dams having problem woody plant growth. This chapter summarizes the collective state and federal attitude, and practice toward woody plant growth on dams.

Problems Caused by Trees and Woody Plants

Of the 48 states that responded to the above seven questions (Alabama and Delaware did not reply), all state dam safety officials indicated that they consider trees and plant growth on dams to be a safety problem. One eastern state dam safety engineer goes so far to say that trees are probably the major problem that he has to deal with. He notes further that most of the trouble occurs because owners (and some engineers) do not recognize trees as problems and become complacent as trees slowly grow into serious problems. Both state and federal officials agree that trees have no place on dams. Federal agencies like the Corps of Engineers, U. S. Bureau of Reclamation, and TVA, which own, operate and maintain their own dams, do not allow trees to grow on their structures. Figure 2 shows a problem dam in Nebraska where tree roots have been reported to penetrate the chimney drain and thus affect the operation of the dam.

Figure 2. Example dam with problematic trees in Nebraska.

Figure 3. Example dam with inspection-hindering trees in Tennessee.

The problem most commonly noted by state officials is that trees, woody vegetation, briars, and vines interfere with effective safety inspections. Figure 3 illustrates this problem for a dam located in Tennessee.

Figure 4 gives a breakdown of the percentage ranges of regulated dams where the 48 reporting state dam safety officials shown in Figure 1 estimate that trees and brush hinder safety inspections in their respective states (ASDSO, 1999). While half the states report having only 20 percent or fewer dams with significant trees and woody vegetation that hinder inspections, vegetation on an estimated 30,000 or nearly a third of the collective state-regulated dams, is reported to obstruct effective dam safety inspections.

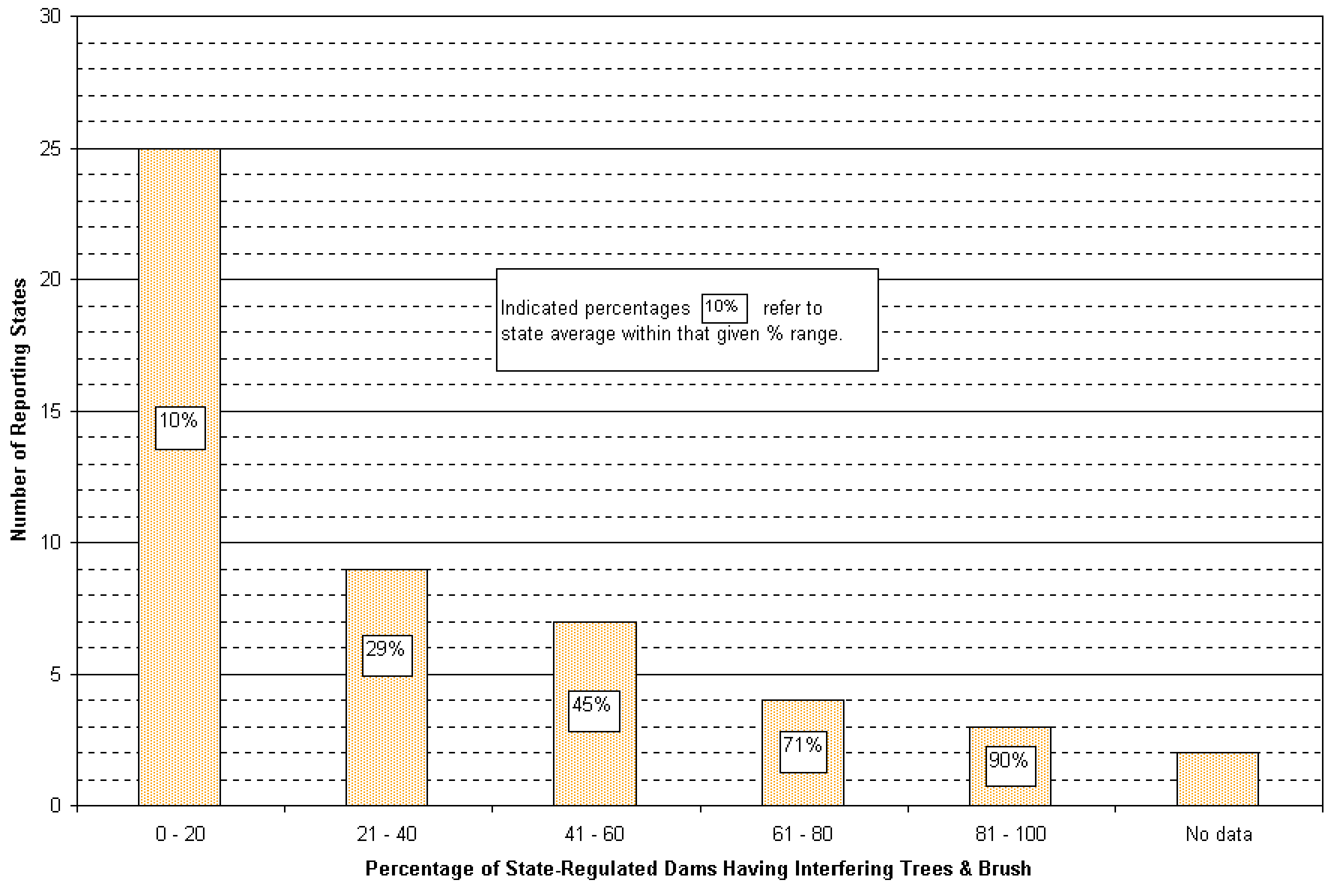

Figure 4. Estimated percentages of state-regulated dams where trees and brush are considered a deterrent to effective safety inspections.

Other dam safety problems caused by woody vegetation growth are:

- Uprooted trees that produce large voids and reduced freeboard; and/or reduced x-section for maintaining stability as shown in Figure 5.
- Decaying roots that create seepage paths and internal erosion problems.
- Interfering with effective dam safety monitoring, inspection and maintenance for seepage, cracking, sinkholes, slumping, settlement, deflection, and other signs of stress

Figure 5. Serious damage by uprooted tree to embankment stability at a dam in Oregon.

- Hindering desirable vegetative cover and causing embankment erosion
- Obstructing emergency spillway capacity
- Falling trees causing possible damage to spillways and outlet facilities
- Clogging embankment underdrain systems
- Cracking, uplifting or displacing concrete structures and other facilities
- Inducing local turbulence and scouring around trees in emergency spillways and during overtopping as shown in Figure 6.

Figure 6. Tree root induced scouring on crest and downstream face of Coffey dam in Kansas.

- Providing cover for burrowing animals
- Loosening compacted soil
- Allowing roots to wedge into open joints and cracks in foundation rock along abutment groins and toe of embankment, thus increasing piping and leakage potential.
- Root penetration of conduit joints and joints in concrete structures

Current Policies and Procedures

Twenty-four of the 48 responding states noted that they had formal policies and/or operating procedures for addressing tree and woody plant growth issues. These policies usually include one, or some combination, of the following:

- Trees are not allowed to grow on dams or near toe and abutment
- All trees and stumps must be removed, but roots may be left
- All trees, stumps, and roots must be removed
- All trees must be removed, but root systems of "small" trees may be left; root systems of "large" trees must be removed
- Dams are treated on a case-by-case basis -- usually under the direction of a qualified professional engineer.

For those states that choose to distinguish between "small" and "large" trees, the definition basis ranges from two to eight inches in diameter; most use a size of four or six inches in carrying out their policies.

Of the remaining 24 states indicating that they have no formal policies or procedures, the range of recommended procedures to dam owners varies widely. Some states evaluate dams on a case-by-case basis, while other states require owners either to maintain their dams, to remove vegetation for inspection, or to use other means for dealing with plant problems such as requiring a qualified engineer to be retained, depending on the dam hazard classification.

In summary, states follow several schools of thought and considerations in dealing with trees and vegetation on existing and new dams:

Existing Dams:

- Distinguish between "small" trees and "large" trees
- Remove all trees, stumps, and roots from dam embankment
- Cut trees to ground level, but leave stumps and roots
- Cut trees, remove stumps, but leave roots
- Consider case-by-case basis
- Breach, remove, or decommission dam
- Require retention of a qualified engineer by owner
- Do nothing.

Figure 6. Trees cut prior to removing stumps and roots from dam.

Chapter 4: Dam Remediation Design Considerations presents recommended procedures for removal of trees and dealing with tree and woody vegetation related problems.

Figure 7. Completed remediation job after removing stumps, seeding, fertilizing & mulching.

Figures 6 and 7 illustrate extensive efforts necessary to restore a heavily wooded earthen dam to a desirable vegetated and maintained condition.

New Dams:

- Establish effective ground cover and hope for the best in continual maintenance
- Use vegetative barriers such as bio-barriers, or use silvicides/herbicides/chemical treatment.

Constraints to Removing Trees and Plants

Several state and federal dam safety officials reported constraints to removing and/or controlling unwanted trees and other vegetation. Constraint categories explicitly cited by state dam safety officials (number of states in parentheses) are given below:

- Financial limitations by owners (13 states)
- Environmental regulations and/or permits (10 states)
- Legal issues (6 states)
- Aesthetics (5 states)
- Threatened/endangered species issues (2 states)
- Media (1 state)
- Sentimental reasons (several).

States indicated that the greatest constraint to removing unwanted trees and plants and repairing a structure infested with roots is limited financial capability by the owner. States such as Kentucky try to work with the owner to minimize the financial burden without threatening public safety. Ohio has recently established two low-cost loan programs to assist qualified public and private dam owners in funding safety-related improvements to their dams, including repairs mandated by the state dam safety program.

Environmental constraints range from limitation of the use of certain herbicides or chemicals for controlling vegetation and for treating stumps and/or roots near water bodies; to prohibition of, or air quality concern for, burning cleared vegetation. Unless exempted, vegetation removal and maintenance around dams may conflict with wetland protection regulations. In Washington, environmental issues can pose a major hurdle to removing trees, but ultimately, public safety takes precedence over environmental concerns. In Arizona, problems with time-consuming environmental permit requirements for larger plant removal projects are sometimes encountered.

Some states have limited legal power to force owners to remove trees and vegetation from dams. This lack of authority may cause delays and expensive and time-consuming litigation to obtain an order. Other states, like Maine, do not have specific laws that force owners to remove vegetation from their dams, and removal orders have yet to be tested. One state, South Carolina, notes that if the owner will not voluntarily cut or remove unwanted vegetation, the only course is to start legal action against the owner. Because legal help is limited, such help is normally requested for the "most extreme cases." This means that only a few owners can be forced to do something about their vegetation. In New Hampshire, legal assistance is sometimes necessary to perform enforcement functions. In Oregon, if there is a problem with a recalcitrant owner, a Proposed Order can be initiated by the Oregon Dam Safety Program to correct the situation if it is determined to be an immediate threat to the integrity of the structure. However, this process can be rather lengthy and expensive when staff time, materials, and attorney fees are included in the costs of preparing for a contested case hearing. In the end, most dam owners have the right to contest state directives to remove trees and other plants through administrative and legal processes and judicial appeals.

In some states, concerns have arisen when dams are located in parks or environmentally sensitive areas, especially when endangered or threatened species habitat is involved, in turn creating legal constraints.

Aesthetics and sentimental reasons are often used by dam owners and their neighbors to resist removing trees and undesirable vegetation. This is particularly true if owners have intentionally planted ornamental trees and shrubs on their dams to provide shade or fruit, or to improve looks. Some owners believe that the more woody vegetation on a structure, the better -- thus making it very difficult for state dam safety officials to request its removal.

The power of the press has had major influence on tree removal programs in some cases, especially where the target dam is owned by a poor or downtrodden citizen or insolvent municipality. Heated controversy between public safety interests and private owners or interest groups was generated through various newspaper stories and letters to the editor in 1990 over the removal of 500 mature cottonwood trees on two dams owned by an 85-year-old widowed rancher who at the time was suffering from serious illness. The news stories, which cast the owner as being targeted because she was vulnerable, influenced the owner's neighbors to encourage her to take a stand against further removal of 500 remaining trees because they felt that enforcement of the state dam safety act "would cause more harm than good."

While these constraints affect the ability of many states to enforce their regulations, some states such as Arkansas, Georgia, Colorado, Iowa, Maryland, Montana, New Jersey, North Carolina, and Tennessee report no major constraints to enforcement and consider the safety of dams to be of primary importance.

Federal agencies appear to have fewer constraints than states relative to mandating the upkeep and maintenance of jurisdictional dams. However, some federal agencies noted that they must make sure that they comply with the National Environmental Policy Act and the Endangered Species Act prior to initiating tree and plant control and management. Isolated constraints at the National Park Service involving funding priorities, historic preservation, and disruption of visitor services may override safe operation and maintenance needs at some dams. Local watershed districts that are often poorly funded are responsible for the operation and maintenance of many of the USDA/NRCS flood control dam projects.

Vegetation-Caused Problems and Failures

Figure 8. Exposed tree roots in overtopped dam.

Twenty-nine states indicated documented evidence where vegetation on dams has either caused dam failure or negatively affected their safe operation. Sixteen states had no documented evidence and five states had no response. Several states provided photos (Figure 8) and information on tree caused failures or dam safety problems. The most recent documented dam failure due to tree root penetration occurred in May 1999 at an unnamed Air Force Academy dam near Colorado Springs. Here, an approximately 13-ft. high dam with a pond capacity of less than 5 acre-feet of horse stable waste water failed, releasing its contents and injuring a horse in a stable located about 100 yards downstream. The failure occurred after more than 7 inches of rain had fallen in the previous 72 hours. The dam had several pine trees on its crest and faces, and the breach opening exposed an extensive, deep root system. Roots up to 4 inches in diameter were found in the breach area. Figure 9 shows an example of a large root exposed in the bottom of the channel at the breach. The dam had not overtopped, and the failure was attributed to internal erosion of the decomposed granite embankment material along the roots. A tree had been located directly over the breach.

Figure 9. Large pine tree root located in the channel of the breach opening of a failed Air Force Academy waste lagoon pond dam (David Eyre, Senior Civil Engineer, Air Force Academy, Colorado, 1999).

At the Federal level, USDA/NRCS referred to documented cases where dam failure has been determined to be caused solely by trees, and noted that trees have also masked other more serious seepage problems, which went undetected.

Past and Current Research

Other than a few references to the University of Tennessee Tree Growth Report (Tschantz, 1988), only one or two other citations for tree or woody plant-related research were identified by the state dam safety officials (USDA/SCS, 1981). The surveyed Federal agencies had relatively little to offer in the way of references to current or past research regarding the effects of tree and plant growth on dam safety. The Corps of Engineers referred to geotechnical and other related program research conducted at the Waterways Experiment Station, published as a technical report series, Repair- Evaluation-Maintenance-Rehabilitation (REMR). One recent study for the St. Paul District showed that a hole formed by a blown-down tree in the downstream toe area can produce a potentially dangerous increase in hydraulic seepage gradient and internal erosion or piping problems in dikes (Duncan, 1999). The USDA/NRCS referred to the 1950's research work done at the ARS Hydraulics Laboratory in Stillwater, Oklahoma, on Flow in Vegetative Channels, which could have application to some emergency spillways.

A recent literature review, sponsored by ASDSO/FEMA and conducted for the Steering Committee on Plant and Animal Penetration of Earthen Dams, researched available material on the effects of woody plants on dam safety (Tschantz et al, 1999). All types of sources and searches were inventoried, including ASDSO conference and workshop proceedings, ASCE technical journals and articles, USCOLD, direct e-mail and telephone contacts of selected federal and state agency officials, universities, research laboratories and other data bases accessible through the National Technical Information Service (NTIS) and National Performance of Dams Program (NPDP). While only a few references were found on recent or current research of tree and plant effects on dam safety, several references on federal and state practices, policies, and procedures for dealing with trees and vegetation were cited in such topical areas as:

- woody plant physiology
- documented examples of woody plant-caused dam failures, operation, and maintenance problems
- case histories related to tree-caused dam failures
- current and past federal, international, and other research activities
- federal, state, international, and other organizations' policies, procedures and practices for preventing and remediating woody plant problems, and
- federal, state or private cost documentation for removing or controlling trees and woody plants.

Costs of Removing Trees and Tree Related Remediation

Limited cost information for removing trees and brush or for repairing damages caused by vegetation at dams was available from the states or federal agencies. Most state dam safety officials indicated either that they did not have the data or that the owner or his consultant would have that information. Virginia reported that, while costs can be nominal, in extensive tree growth situations where grubbing is required, $10,000 to $20,000 per dam is common and that at one dam; the tree-clearing cost was about $40,000. Missouri reported that such costs could range from $1,000 to $10,000 depending on how badly the dam is overgrown with trees. A prominent North Carolina geotechnical engineering firm stated that ten different contractors, working in North Carolina, South Carolina, and Georgia, reported recent bid prices ranging from about $1500 to $3000 per acre for cutting trees at ground level, removing stumps and root balls, and grubbing the area to remove perimeter roots. Contractors were advised that clearing and grubbing would be done on embankment slopes ranging from 1.5:1 (Horizontal to Vertical) to 4:1 (Horizontal to Vertical), within possible wet areas in the lower 1/3 to 1/2 of the downstream slopes, and on earthen dams ranging in height from 25 to 50 feet. Table 1 compares cost experiences reported by state dam safety officials in different regions of the country for clearing and grubbing trees from dams.

Reporting State	Number of Dams	*Cost per acre	Survey Comments
Georgia	More than 25	$1,000 to $5,000	Based on consultants' feedback; cost varies depending on dam face conditions such as slope steepness, degree of wetness and tree density.
Oklahoma	1 1	$900 $1,150	2 acres of d/s slope over 2-1/2 day period 3-1/2 acres, current proposal estimate.
South Dakota	Several	$100 to $200/Acre	Usually 10 - 20 trees per dam
Nevada	1	$532	Based on 3 hourly laborers working for 2 weeks on 3.25 acres of willow & mesquite removal on d/s dam face (~1995)
Michigan	General DNR construction cost experience	$3,500 $6,000 $12,000	Light clear/grub (diam.<6") Medium clear/grub (diam.<12") Heavy clear/grub (diam<24")
Tennessee	7	$1,540 (Ave.) (approx. range = $1030 to $3290)	Total clearing, grubbing & reseeding cost for 7 dams = $16,705 @ ~1.5 acres per dam. Jobs included range of tree sizes & heavy brush. (1995-98)
Texas	1	$5,500	Part of overall site clearing and grubbing contract for new dam in East Texas (1995)
Ohio	1	$10,000	Cost included clearing, grubbing, mulching and seeding. Heavily wooded; hundreds of trees removed from d/s slope (1999)
Minnesota	Current estimates from Minnesota consultant Small Projects	$1350 $2800 $4475 $4225 $6775 $960	Clearing brush with brush saw - no grubbing Clearing brush by hand - no grubbing Clear and grub brush, incl. stumps Cut & chip up to 6" trees; grub/remove stumps Cut & chip up to 12" trees; grub/remove stumps 16 m-hrs @ $60/hr to clear and grub small trees (diam. < 6") for less than one acre projects

*Reported costs not indexed

Table 1. Cost Comparisons for Clearing, Grubbing and Removing Trees from Dams.

While the range of remedial costs varies widely, depending on several factors, it appears that about $1,000 - $5,000/acre may be a reasonable baseline to use for rough estimating purposes, with the lower figure applicable to small and low-density tree growth and the larger figure appropriate to mature, very dense tree stands.

A typical 25-foot high by 750-foot long earthen dam having 3:1 (Horizontal to Vertical) embankment slopes, a 15-foot crest width, and a freeboard of 10 feet above normal pool has approximately two acres of exposed crest and face area for potential tree growth. Total costs for clearing and grubbing trees for such a dam would be in the range of $2000 to $10,000 depending upon the local site conditions.

Several site-specific factors can influence tree removal costs. These include size and type of trees, growth density, total job size (number of acres), location of growth (crest and/or both faces), embankment slope steepness, slope condition (such as degree of wetness or surface texture), degree and type of required surface treatment (backfilling, use of herbicides or bio-barriers, mulching, seeding, fertilizing, etc.), and regional labor and construction indices.

The U. S. Bureau of Reclamation reported detailed cost data using three herbicidal application methods (aerial, cut-stump, and ground-based foliar-application) in its 1987-93 program to control salt cedar along waterways in seven states of the Upper Colorado Region. Application costs ranged from about $60/acre for aerial spraying to about $1000/acre for cut-stump and spray methods (Sisneros, 1994). The National Park Service indicated that it has done tree removal with the assistance of the U. S. Bureau of Reclamation, but cost information is not readily available.

Summary

Trees appear to be a major dam safety issue for many states. Based on recent survey responses from 48 states, it is estimated that about one half of the state-regulated dams have trees growing on them. The same reporting states estimate that an average of nearly a third of the dams that they regulate have sufficient trees, brush and other growth to hinder effective safety inspections.

Current state and federal policies, procedures, and practices relating to tree and woody plant removal, control, and management for dam safety are generally fragmented and inconsistent among state and federal dam safety agencies**.** ***However, all state and federal agency dam safety officials and experts agree that trees have no place on dams and need to be managed and controlled on both existing and new dams for at least three important reasons:*** (1) trees and dense vegetation hinder effective dam inspections; (2) tree roots can cause serious structural instability or hydraulic problems, which could lead to dam failure and possible loss of life; and (3) trees and brush attract burrowing animals, which can in turn cause serious structural or hydraulic problems.

The fragmentation among state and federal agencies applies only to procedures about ***how*** and ***to what extent*** the trees and their roots should be removed and resulting cavities remediated to ensure a hydraulically and structurally safe dam. Other chapters in this ***Manual*** present methods and practices for controlling trees and woody plants and for remediating damage caused by trees and other woody plants.

While limited information is available, a sampling of state dam safety officials and other experts report that the cost of removing trees and brush from the face of a dam can broadly range from about $1,000 to $10,000 per acre, depending on several factors. Typically, the cost of clearing and grubbing trees from dams falls into the $1,000 - $5,000 per acre range. The broad range of costs is not surprising as most dam safety engineers agree that tree removal costs are very much site specific. Controlling vegetation annually is relatively inexpensive, but removing trees on and repairing damage to neglected dams may cost owners several thousand dollars.

Most dam safety experts agree that research needs to be done on determining the relationship of plant and tree species to root penetration of artificial environments such as embankment dams; the interaction between root systems and the phreatic zone and surface; and development and understanding of various types of physical, biological, and chemical treatment and barriers for controlling root growth. Because many existing dams exhibit dense growths of trees and woody vegetation with deep-penetrating root systems, engineering methods need to be developed for understanding, predicting, and stabilizing the effects of these root penetrations to minimize internal erosion and failure. Dam safety experts agree that both technical and non-technical pamphlets and brochures, practice manuals, web-based documents, workshops, and guidance materials need to be developed for educating dam owners about the problems caused by trees and woody vegetation. Engineers, dam safety officials and inspectors, developers, and contractors must be provided technical training and information relative to the control and/or safe removal of trees and other undesirable woody vegetation from earthen dams.

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Chapter 3
Tree Growth and Tree Root Development Requirements

The purpose of this chapter is to provide the reader and user of this ***Manual*** with a basic understanding of plant physiology related to fundamental processes of tree growth and tree root development. It is not the intent of this chapter to delve into a detailed biological study of trees and woody vegetation, but to provide the reader with a fundamental understanding of the requirements for tree growth and tree root development while attempting to dispel some of the misconceptions and myths associated with tree and woody vegetation growth, particularly as related to tree root development.

Common Myths and Misconceptions

There are many misconceptions and common myths relating to trees and woody vegetation that have been accepted by many people without a scientific basis. Many of these common myths and misconceptions relative to plant physiology have originated from uneducated interpretations of observations associated with tree growth and tree root development. Some of these myths and misconceptions associated with trees and woody vegetation affect correct interpretation and understanding of the impact of such growth on the safety of earthen dams. The more common myths and misconceptions must be dispelled so that a new level of understanding about the impacts of trees and woody vegetation on earthen dams can be properly developed. Trees and woody vegetation, like all living things, must have oxygen, nutrients, and water (moisture) to survive. Without these requirements, tree roots cannot continue development and tree growth cannot continue. The root system of trees and woody vegetation is in simplified terms comprised of two major components that are the root ball, typically directly below the trunk of the tree, and the lateral or perimeter transport root system that typically extends beyond the 'drip line' or vertical projection of the canopy of the tree.

Tree Tap Roots are thought by many to be the primary root system for all ages and types of trees and woody vegetation. In fact, the taproot is the first root to develop from the seed or reproductive source. This central root is an extension of the stem and differs from the stem only in that the root contains nodes for development of additional roots. Once the taproot has stabilized the young plant (tree), the root ball begins to develop and the taproot becomes less important than other roots that grow laterally from the taproot. The developing root ball provides vertical support for the tree as well as providing nutrients and water (moisture) to the tree. Roots extending laterally from the root ball increase the stability of the tree while functioning to collect and store nutrients, oxygen, and water for the tree. While it is true that some trees have more clearly defined taproots, taproots of most trees do not extend significantly far below the massive root ball of healthy trees. However, taproots are more predominant in locations where trees grow in deep deposits of loose dry soils.

Tree Root Soil Stabilization is likely the most common misconception associated with tree growth and tree root development. How many times has the reader heard, or perhaps mistakenly said, **"If it were not for those trees and tree roots this slope would really be eroded or unstable – those tree roots are really 'holding' that soil slope"**. Many otherwise knowledgeable and educated individuals believe the myth that tree roots actually stabilize soil masses by 'holding' the soil together. This misconception leads many people to believe that heavy tree and woody vegetation growth is actually beneficial for steep embankment slopes. Tree root development that is necessary to provide nutrients for tree growth and stabilize the tree actually loosens the soil mass. Laterally extending tree roots could be thought of as being nature's original application of the geotechnical engineering design concept of soil nailing. ***Root penetration stabilizes the tree and loosens the soil mass within which the tree roots are developing; the converse is a myth and certainly not true.***

Groundwater Penetration by tree root systems is another common myth and misconception believed by many otherwise knowledgeable individuals. Although Cypress, Tulip Poplar, some Willow and Water Birch tree species appear to have root systems that are submerged, nutrient root systems of trees cannot survive beneath the water table or the phreatic surface (seepage line) in an earthen dam. Trees and woody vegetation depend upon their transport root systems to provide the major portion of the oxygen demand for continual tree growth and tree root development. Most species of trees and woody vegetation quickly die of suffocation once the lateral transport root system and root ball are inundated. This phenomenon can be visually observed in many areas of Arkansas, Mississippi, and Louisiana where large tracts of timber have been artificially flooded for duck hunting. If these flooded tracts of timber are not drained seasonally, the timber (trees) die as a result of suffocation. Similarly, beaver activity causes significant losses in the timber industry every year as a result of inundation of harvestable timber. Tree roots do not penetrate the water table or the zone of saturation where oxygen demands of the tree cannot be met. If the zone of saturation or water table is raised above the level of tree roots for an extended period, the tree will die as a result of suffocation. Tree root development and tree growth cannot occur when moisture contents in the soil mass are greater than about forty percent.

Soil Moisture Uptake of many species of trees far exceeds that which most individuals would estimate as a normal requirement of water for continual tree growth and tree root development. It is not uncommon for most species of healthy mature trees to absorb 200 to 300 gallons of water per day if this amount of water is available to the lateral transport root system. Reduced availability of soil moisture will curtail continual tree root development until such time that the soil mass is replenished with sufficient moisture to allow resumption of tree root development. Tree root development and tree growth cannot occur in soil masses having moisture contents less than about twelve percent for extended periods.

Woody Vegetation Control Versus Dam Performance is an issue that is clearly misunderstood by many dam owners, operators, inspectors, dam safety regulators, engineers, and consultants. Tree and woody vegetation root penetration is not a beneficial effect on the performance of earthen dams. As indicated previously, tree root penetration does not stabilize a soil mass, particularly an embankment slope. Quite the contrary, tree root penetration loosens the soil of an embankment slope and creates a condition more conducive to surface water penetration and slope failure. Earthen dams are not unlike other engineered structures in that they must be properly maintained in order to perform as perceived in the original design of the structure.

When does routine vegetation maintenance and control become a dam safety and/or dam performance issue? The author is of the opinion that vegetation maintenance and control on an earthen dam ends, and the need for an ***engineered*** earthen dam rehabilitation plan begins, when effects of an improper vegetation maintenance and control program create conditions that are ***detrimental to the structural integrity*** of the earthen dam. For example, an earthen dam that exhibits a dense growth of grasses and weeds that are waist high, but is free of significant woody vegetation growth, is an earthen dam that is in need of proper vegetation maintenance and control to allow proper inspection of the dam. However, waist-high grasses and weeds would not typically affect the structural integrity of the earthen dam. Conversely, an earthen dam that supports a dense growth of four to eight inch diameter trees that preclude proper access for inspection is a dam safety and performance issue. Dense growths of trees and woody vegetation not only present a hindrance to proper dam safety inspection, but also are detrimental to the structural integrity of the earthen dam. Proper removal of trees and woody vegetation from earthen dams is a dam safety and performance issue that must be conducted in accordance with properly designed dam remediation plans and specifications.

Tree Root Characteristics and Requirements

As previously indicated, root systems of trees and woody vegetation consist of two primary components that are the root ball and the lateral transport root system. While all tree and woody vegetation roots have a primary function of providing oxygen, nutrients, and water to the plant, they also provide stability for the plant. The root ball that is typically directly below the trunk of the tree provides vertical support while the lateral transport roots provide lateral support for the tree. Root systems of trees and woody vegetation growing on dam embankment slopes will typically be asymmetrical as a result of the need for the tree to be stabilized in the sloping embankment soil mass. The lateral transport roots will typically be better developed on the uphill side of the tree than on the downhill side of the tree. Dr. Kim D. Coder at the University of Georgia has conducted extensive studies and research on tree growth and tree root development requirements and characteristics. He has developed data from these studies and research programs that relate tree trunk size to root ball diameter and lateral transport root system diameter. These data are presented in Table 1 below.

Table 1: Typical Rootball and Root System Sizes for Various Tree Sizes

Tree Diameter, inches	Rootball Diameter, feet	Root System Diameter, feet
4 to 5	6	10 to 12
6 to 7	8	16 to 18
8 to 9	10	20 to22
10 to 11	12	26 to 28
12 to 14	14	30 to 32
15 to 18	16	38 to 46
19 to 23	18	48 to 58
24 to 36	20	60 to 90
37 to 45	22	92 to 112

During the presentation of common myths and misconceptions about tree growth and tree root development, requirements of trees and woody vegetation for continual growth and root development were discussed. Based upon research and studies conducted by Dr. Kim Coder, requirements for tree and woody vegetation growth and root development are tabulated in Table 2.

Table 2: Root Growth Resource Requirements

Requirement	Minimum Value	Maximum Value
Soil Oxygen Content	**2.5%**	**21.0%**
Soil Air Voids	**12.0%**	**N/A**
Soil Bulk Density (Clays)	**N/A**	**87 pcf**
Soil Bulk Density (Sands)	**N/A**	**112 pcf**
Water Content of Soil	**12.0%**	**40.0%**
Limiting Soil Temperatures	**40ºF**	**94ºF**
Soil pH Values	**3.5**	**8.2**

Soil air void content is one of the most critical factors for continual tree root development. This factor is critical since both soil density and soil oxygen content are dependent upon the amount of air voids present in a soil mass. Because of the importance of soil air void content, Dr. Coder conducted extensive research to determine limiting air void contents for various soil types required for continual tree root growth (See Table 3).

Table 3: Limiting Soil Air Voids for Root Growth in Various Soil Types/Textures

Soil Type/Texture	Air Voids, %
Sand	**24**
Fine Sand	**21**
Sandy Loam	**19**
Fine Sandy Loam	**15**
Loam	**14**
Silt Loam	**17**
Clay Loam	**11**
Clay	**13**

Utilizing weight-volume relationships for various soil types and textures, Dr. Coder was able to determine the limiting (maximum) dry density of soil that would allow continual tree root development. Results of these correlations between minimum soil air void content and maximum soil dry densities required for continual tree root development are presented in Table 4 below.

Table 4: Limiting Soil Dry Density for Root Growth in Various Soil Types/Textures

Soil Type/Texture	Dry Density, pcf
Sand	112.3
Fine Sand	109.2
Sandy Loam	106.1
Fine Sandy Loam	103.0
Loam	96.7
Silt Loam	90.5
Clay Loam	93.6
Clay	87.4

In an attempt to relate the research data developed by Dr. Coder to geotechnical engineering data developed from over 200 earthen dam projects, the author has compiled a comparative list of soil properties for various soils that have been found in earthen dam embankments. The ranges given in the data presented in Table 5 below are associated with soil in a loose condition and soil in a compacted state that might be required in the construction or remediation of an earthen dam. ***The user of this Manual must be aware that these soil parameters are typical values and should not be relied upon for design of new earthen dams or design of remediation plans for existing dams.***

Table 5: Summary of Typical Soil Parameters

Soil Type	Specific Gravity	Void Ratio	Porosity, %	Dry Density, pcf	Permeability, cm/sec
Sand	**2.62 to 2.66**	**0.40 to 0.90**	**30 to 45**	**90 to 115**	**0.01 to 0.0001**
Silt	**2.60 to 2.68**	**0.50 to 1.20**	**35 to 55**	**75 to 110**	**0.001 to 0.00001**
Clay	**2.66 to 2.72**	**0.60 to 1.40**	**40 to 60**	**70 to 105**	**0.0001 to 0.0000001**

As one can see from the tabulated summary of typical soil parameters, continual tree root development cannot occur in soils that are well compacted. One of the best methods of controlling tree and woody vegetation growth on new earthen dams and existing earthen dams where remediation requires placement of additional embankment fill soil is to compact the embankment fill soils to a high degree of compaction. Increased compaction of embankment fill soils reduces the air void content and limits the amount of surface water that can infiltrate into the embankment slope. However, a good ground cover of grasses can be established in well-compacted soils since the depth of grass root penetration is minimal and the surficial soils will typically sustain the shallow grass root penetration.

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Chapter 4
Earthen Dam Safety Inspection and Evaluation Methodology

The purpose of this chapter is to illustrate dam behavior during the initial years of design life and to present a suggested inspection and evaluation methodology. An example earthen dam configuration will be presented in order to illustrate earthen dam behavior and to develop the suggested inspection methodology.

Example Earthen Dam Configuration

The example earthen dam is assumed to be a high-hazard dam having a structural height of about 33 feet and impounding a lake area of about three acres at normal pool elevation. The contributing watershed of the lake is about 320 acres (0.5 square mile) with a base flow of about one-half (0.5) cubic feet per second (cfs).

The configuration of the example earthen dam consists of an upstream slope of 2:1 (horizontal to vertical), a crest width of fifteen feet, and a 3:1 (horizontal to vertical) downstream slope. The dam has a freeboard of four feet making the hydraulic height of the dam about 29 feet. The dam is founded on relatively impervious (compared to the embankment fill soil) material with a down gradient slope of about three percent. The example earthen dam section has a key trench directly below the centerline of the dam crest that has a bottom width of ten feet and side slopes of 1:1 (horizontal to vertical). The dam crest has a two-percent slope toward the impounded lake and the upstream slope has no protection system against tree and woody vegetation growth or wave erosion. The embankment of the example earthen dam is assumed to be homogeneous. Figure 1 is a representation of the example earthen dam configuration with the theoretical seepage line intercepting the downstream slope at about one-third the hydraulic height of the dam. **Rule-of-Thumb:** ***The phreatic surface intercepts the downstream slope of a homogeneous earthen dam at a vertical distance of about one-third the hydraulic height above the toe of the downstream slope, provided there is no internal drainage system in the dam embankment.***

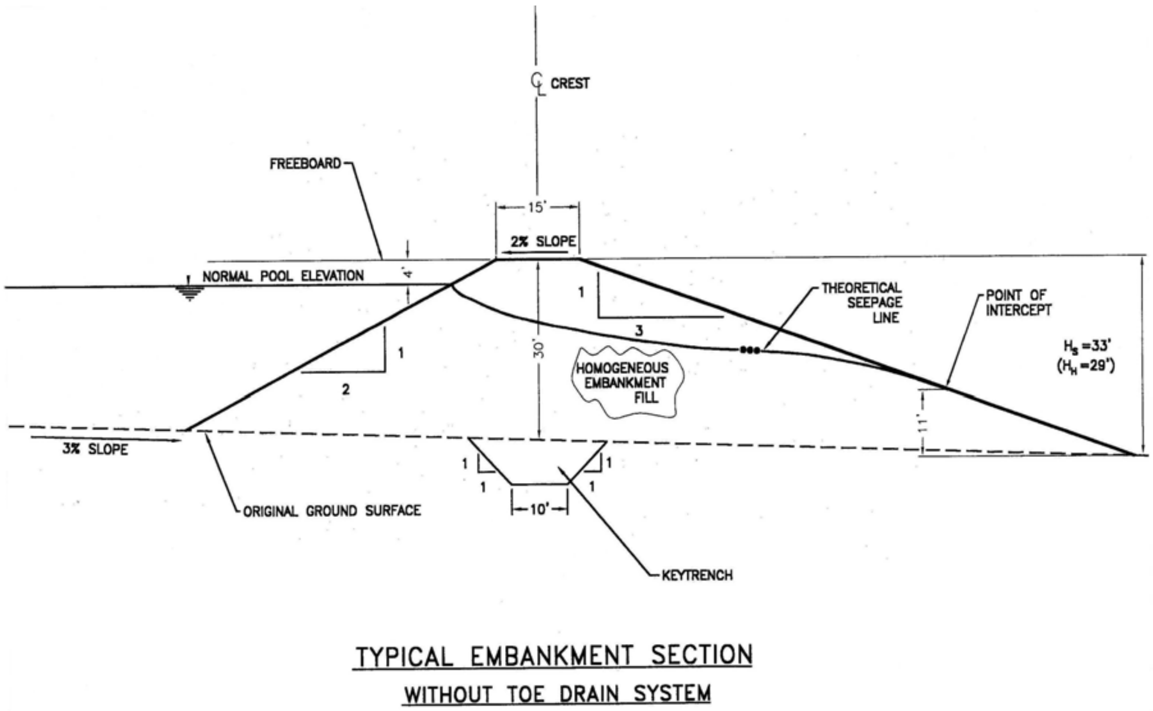
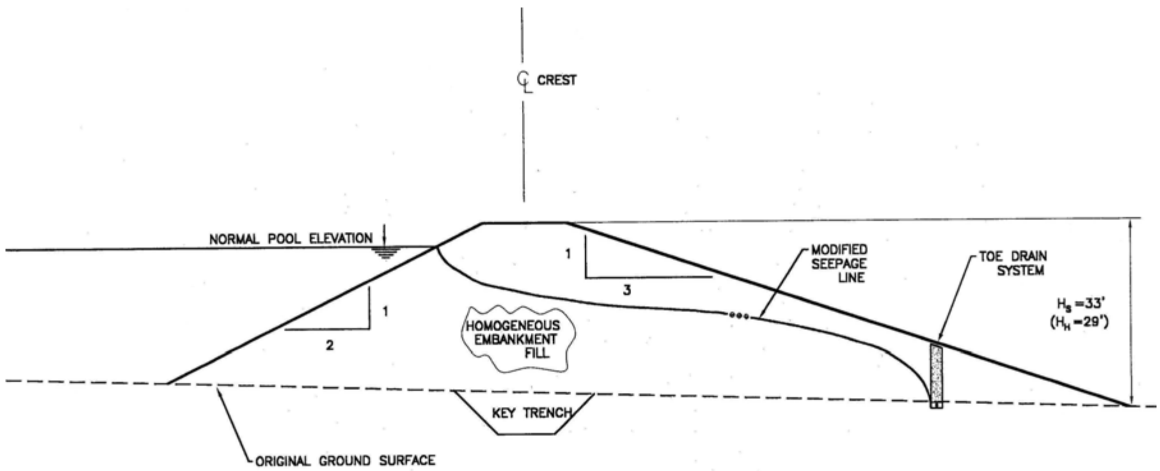


Figure 1

Based upon data provided for the example earthen dam, this dam would be listed on the National Inventory of Dams (NID). In addition, the example earthen dam would be classified as a small-size, high-hazard dam by most state dam safety regulations**.**

Figure 2 illustrates the example earthen dam with an embankment subdrain system located within the downstream embankment slope. The subdrain or embankment drain system is located at about the point of interception of the seepage line with the downstream slope if there was no embankment toe drain system within the downstream slope. As a result of the presence of the embankment subdrain system, the seepage line through the dam embankment has been modified (lowered) from the location of the theoretical seepage line for a homogeneous earthen dam embankment. The seepage line within an earthen dam is often mistakenly considered to have a permanent location.

However, the location of the seepage line is continually changing as a result of many influential factors. Fluctuations in the pool elevation, seasonal and long-term climatological conditions, and the growth of trees and woody vegetation in close proximity to the seepage line are some of the factors that influence changes in the location of the phreatic surface within an earthen dam embankment.



TYPICAL EMBANKMENT SECTION
WITH TOE DRAIN SYSTEM

Figure 2

Important moisture regimes other than the steady-state seepage line (phreatic surface) are often not given proper consideration in the evaluation of the performance of earthen dams. The ***zone of saturation*** is located immediately above the phreatic surface or seepage line where embankment fill soils have become saturated as a result of capillary rise caused by capillary forces in the soil voids. Figure 3 illustrates the presence of zones of saturation associated with that of a theoretical seepage line location without an embankment subdrain system as well as that of a modified seepage line location with an embankment toe drain system. The height of capillary rise (thickness of the zone of saturation) is directly dependent upon the effective mean diameter of soil voids within the earthen dam embankment. The effective mean diameter of compacted soil is dependent upon the ***effective particle size*** (De) of the compacted embankment fill soil. Soil within the zone of saturation is completely saturated; however, there is no flow or gravity induced movement of water unless some external force disturbs the soil. This phenomenon is often observable during the inspection of downstream slopes of earthen

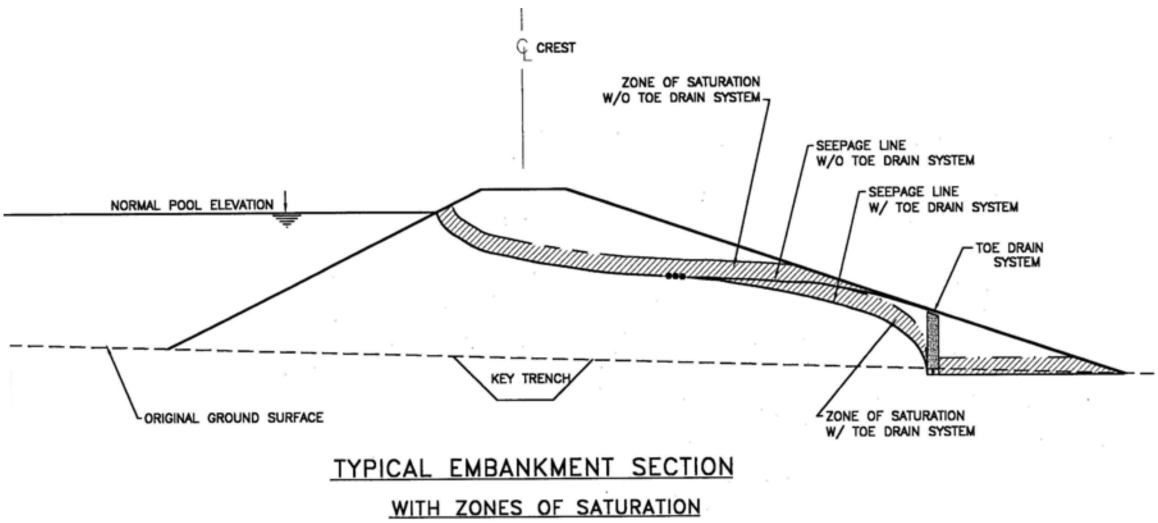


Figure 3

dams. Seepage and free flowing water can be seen on the downstream slope of an older dam below the point of interception of the seepage line if no embankment subdrain is present. Above the point of interception of the seepage line with the downstream slope, the soil is saturated and the Zone of Saturation can be observed for a significant distance above the seepage line intercept in some cases. In the Zone of Saturation, pore water may be observed to fill tracks made in the water-softened embankment soil. However, once the tracks are filled by pore water released from the disturbed soil there will be no continued flow or seepage from the embankment. This condition is often confused with the presence of embankment seepage. Installation of a subdrain location in this situation may lower the phreatic surface relatively quickly; however, months or even years may be required to drain the zone of saturation because of tensile forces or negative pore pressures in the embankment fill soils.

Embankment Wetting, Saturation, and Seepage

Prior to presentation of the behavior and performance of an earthen dam embankment during the initial years of the design life, one must have an understanding of relationships between various velocities of moisture movement and water flow through compacted embankment soils. First, consider the relationship between the optimum compaction moisture content of an embankment soil and other moisture content properties.

Rule-of-Thumb: ***The optimum compaction moisture content as determined by ASTM D-698 (standard Proctor compaction test) is approximately two to four percent below the Plastic Limit (PL) of most soils and about three to five percent below the saturation moisture content of the same soils.***

Compacted soils will typically increase in moisture content from the compaction moisture content to about the PL of the soil relatively quickly after construction of an earthen embankment. The rate of wetting is much greater in soils compacted dry of optimum moisture content than in soils compacted wet of optimum moisture content. Although compacted soils may undergo wetting or increase in moisture content relatively quickly when exposed to a source of water, the rate of saturation is much slower because air trapped in discontinuous soil voids must be dissolved in soil pore water during the saturation process. Embankment wetting and saturation are not associated with seepage or the flow of water through a homogeneous earthen dam; however, relative velocities of wetting and saturation can be related to values of steady-state seepage velocity, permeability, or hydraulic conductivity of compacted embankment soils.

Figure 4 is an illustration of the example earthen dam with relationships between various soil water flow velocities and permeabilities. First, consider the relationship between the vertical and horizontal permeability of a compacted homogeneous embankment soil.

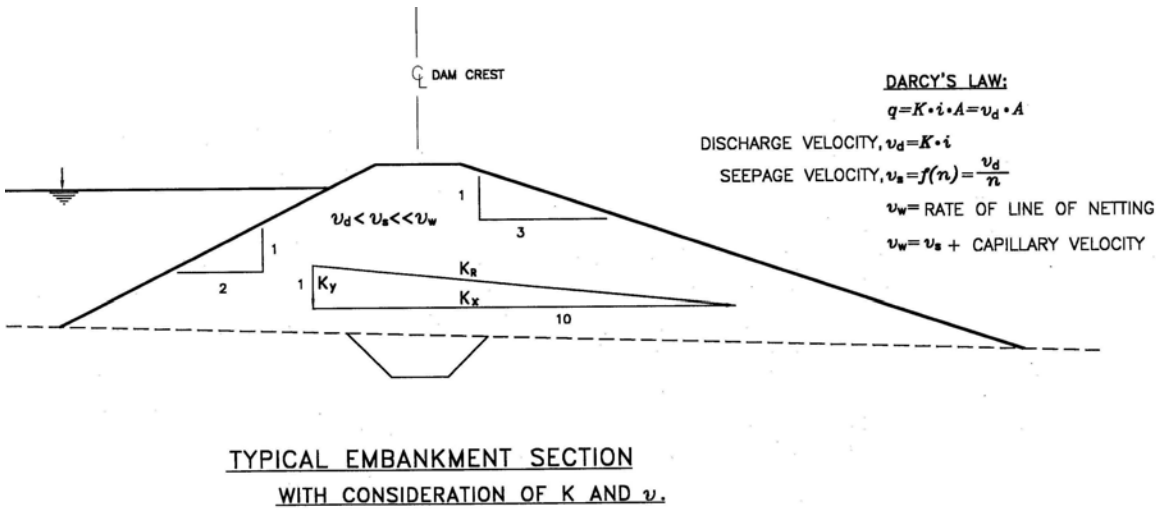


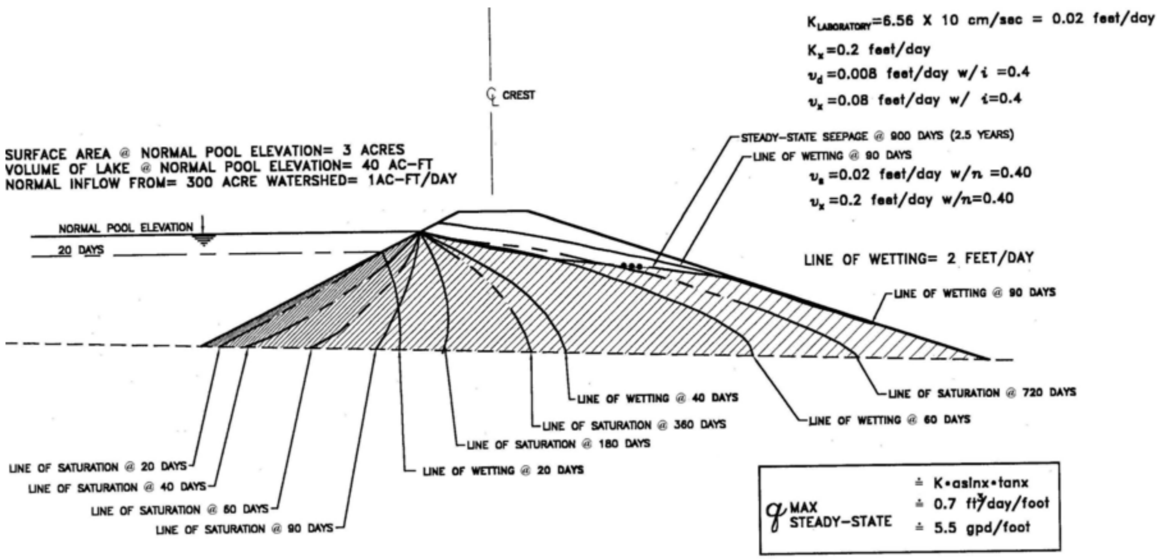
Figure 4

Rule-of-Thumb: ***The horizontal permeability of a compacted homogeneous embankment soils are typically about nine times to ten times (one order of magnitude) greater than the vertical permeability.***

Variation between the horizontal permeability and vertical permeability is the result of the internal structure of compacted soils. This variation does not account for poorly compacted lifts since the embankment is assumed to be homogeneous. Consequently, if laboratory permeability tests indicate that a compacted embankment soil exhibits a hydraulic conductivity value of about 0.000004 centimeters per second (cm/sec) then the horizontal permeability of this compacted embankment soil will be about 0.000036 to 0.00004 cm/sec. Second, consider Darcy's Law that is the basis for all theories and analyses associated with the flow of water through soil masses. Darcy did not account for soil voids relative to soil solids in derivation of his equation. As a result, the area of discharge is the total cross-sectional area through which flow is occurring. If one assumes that the hydraulic gradient producing flow through a soil mass is equal to one (unity), then the ***discharge velocity*** (Darcy's flow velocity) is equal to the permeability value of the soil. The actual flow velocity in the voids of the soil is often identified as the ***seepage velocity*** and is approximately equal to the discharge velocity divided by the porosity value (expressed as a decimal) of the soil. Assuming that the compacted embankment soil in the example earthen dam has a porosity of forty (40) percent (0.40), the seepage velocity of the soil would be about 2.5 times greater than the discharge velocity. Third, consider the wetting velocity or the velocity of the ***line of wetting***. The wetting velocity is the rate at which soil increases in moisture content up to about the PL when exposed to a free water source. The line of wetting can often be observed as it progresses through soil masses, particularly soils that are dry of optimum moisture content. The wetting velocity is the sum of the seepage velocity and the capillary velocity or the velocity of wetting attributable to capillary forces in the soil.

Rule-of-Thumb: ***The wetting velocity or the velocity of the line of wetting through compacted soil is about one order of magnitude (ten times) greater than the seepage velocity.***

Applying this factor to the previous comparison between seepage velocity and discharge velocity, one finds that the wetting velocity is about 25 times greater than the discharge velocity. Based upon the foregoing discussion of earthen dam embankment wetting, saturation, and steady-state seepage velocities, consider the illustration in Figure 5. This figure illustrates embankment wetting, saturation, and steady-state seepage during the early years of the design life of an earthen dam. Assume that laboratory testing indicates that embankment soils of the example dam embankment have a permeability or hydraulic conductivity value of 0.02 foot per day. The discharge velocity would be about 0.008 foot per day with a hydraulic gradient of about 0.4 resulting in a horizontal discharge velocity of about 0.08 foot per day. The associated seepage velocity would be about 0.02 foot per day with a soil porosity of about 40 percent and the horizontal seepage velocity would be about 0.2 foot per day. The velocity of the line of wetting or the wetting velocity would be about 2.0 feet per day.



PROGRESSION OF EMBANKMENT WETTING & SATURATION
WITHOUT CONSIDERATION OF VEGETATION

Figure 5

Based upon the estimated normal inflow from the contributing watershed, the lake retained by the example dam should reach about fifty percent volume in approximately twenty days and reach normal pool elevation in about forty days. Solid lines in Figure 5 illustrate the location of the line of wetting at various time intervals. The line of wetting should reach the downstream slope in about ninety days. ***Note: The compacted embankment soils remain partially saturated after passage of the line of wetting.*** Dashed lines in Figure 5 illustrate the line of saturation at various time intervals. The line of saturation moves at the seepage velocity that is about one-tenth the value of the wetting velocity. When the line of wetting has reached the downstream slope in about ninety days, the line of saturation is still at about the vertical from the intercept of the normal pool with the upstream slope. Based upon this rate of progression, the line of saturation will not reach the surface of the downstream slope and steady-state seepage will not be initiated for about 900 days (about 2.5 years), ***provided that no external influences affect the rate of wetting and saturation***.

The estimated maximum steady-state seepage rate for the example dam will be about 5.5 gallons per day per foot of dam. Before leaving Figure 5, imagine that the example dam contains an embankment subdrain system as indicated in Figures 2 and 3. The rate of progression of the line of wetting and the line of saturation will both be affected by the presence of the subdrain system.

Even without the presence of an embankment subdrain system, the time required for the line of wetting could encompass an entire growing season depending upon the time of year that the dam was completed. More importantly, the time that is required for the line of saturation to intercept the downstream slope might encompass two or three entire growing seasons. Tree and woody vegetation growth can become quite dense and relatively large within the initial two to three growing seasons if not properly controlled.

The initiation of tree and woody vegetation growth on the downstream slope begins the soil moisture uptake cycle so that the line of saturation and the seepage line may never completely develop and intercept the downstream slope. The condition represented by Figure 6 might initially be considered to be beneficial to the stability of the dam embankment. However, one must understand that as the tree and woody vegetation growth continues compacted soils of the dam embankment are continually loosened by the penetration of major tree and woody vegetation root systems. Furthermore, trees that might appear healthy to an untrained inspector may be an unhealthy specimen and have a premature death leaving penetrating root systems to rot inside the dam embankment. Additionally, soil nutrients in the compacted soil embankment of an earthen dam may not be sufficient for development of growth beyond which the tree cannot be properly sustained without premature death. Regardless of the cause, trees and woody vegetation do die and cease to uptake soil moisture that they previously used. This change in soil moisture uptake will affect the zone of aeration, zone of saturation, and the location of the seepage line in the vicinity of the unhealthy or dead trees and woody vegetation.

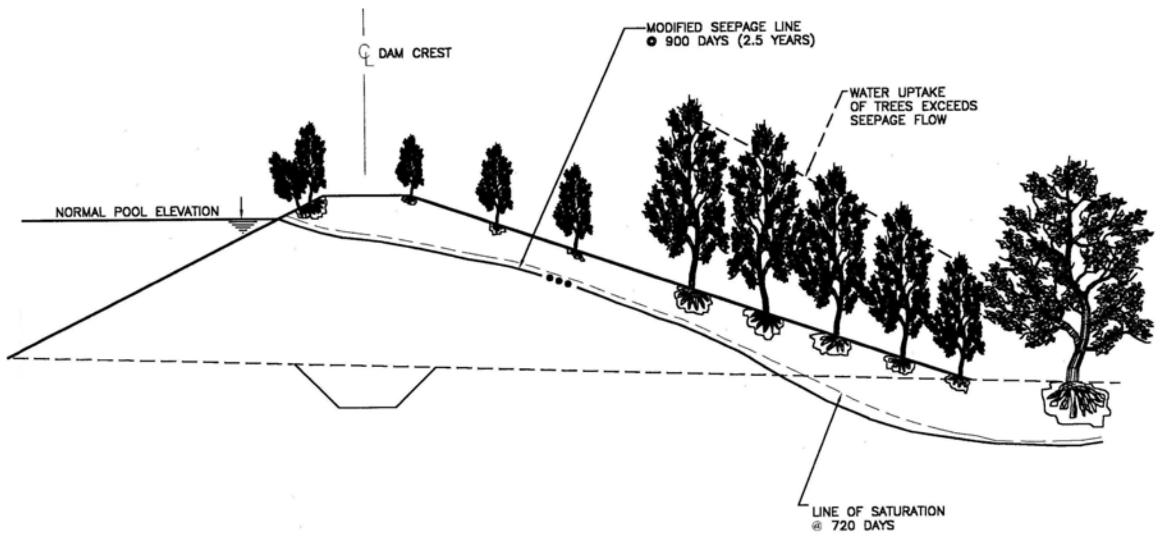


Figure 6

The Mid-Life Crisis of an Aging Earthen Dam

Once an earthen dam embankment has become impregnated with numerous trees and woody vegetation penetrations, routine and even major maintenance activities will likely not be sufficient to regain the original design life of the dam. At this time in the life of an earthen dam, previously identifiable maintenance problems have become serious dam performance and dam safety issues. Restoration through an ***engineered*** dam remediation design and remediation construction is typically required to bring the dam to acceptable standards relative to dam safety requirements.

Figure 7 illustrates some of the problems and dam safety issues that can be created by uncontrolled or non-maintained tree and woody vegetation growth in what has been termed by the author as the ***'Mid-Life Crisis'*** of an earthen dam. Seepage flow may be emerging from rootball cavities of blowdowns (uprooted trees) because they are no longer using soil moisture and the seepage line has adjusted upward toward the surface of

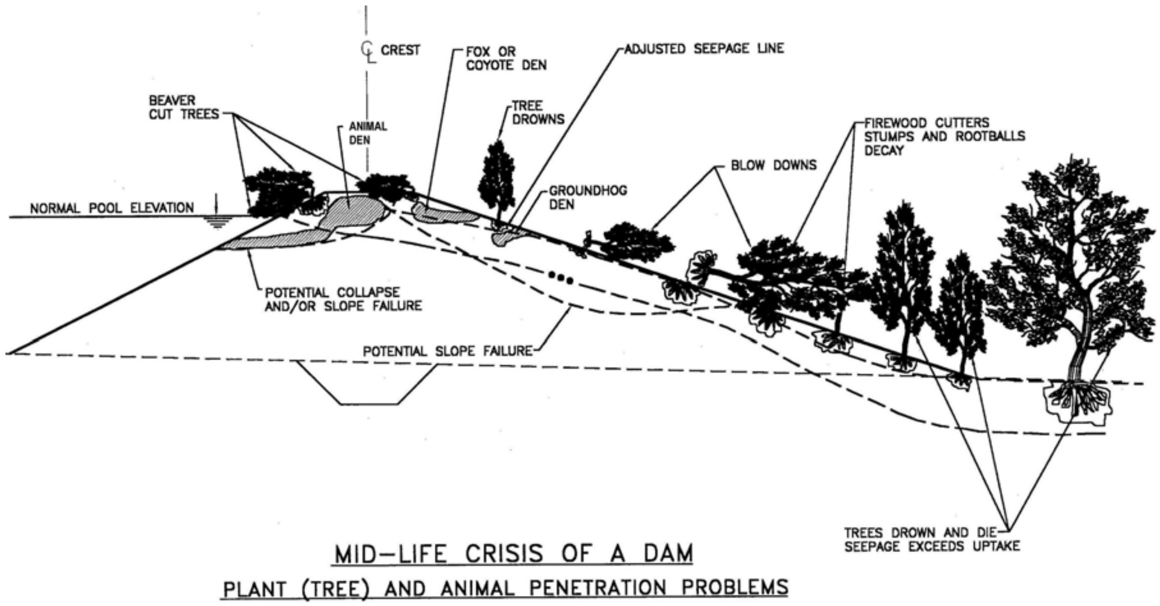


Figure 7

the slope. Removal of mature trees by woodcutters deletes the soil moisture uptake of the removed trees thus further modifying the location of the seepage line closer to the surface of the downstream slope. Rootballs and root systems of otherwise healthy trees located at and beyond the toe of the downstream embankment slope become inundated by the adjusted seepage line. Since trees cannot live through prolonged submergence of their major root systems, these trees will become unhealthy and die leaving decaying rootballs and root systems as serious penetrations in the earthen dam. Rootball cavities remaining from blowdowns (uprooted trees) and their relationship to the seepage line create conditions susceptible to potential slope failure of the downstream embankment slope. Restoration of the example earthen dam illustrated in Figure 7 to a safe condition cannot be brought about through routine maintenance activities. An ***engineered*** dam remediation design and remediation construction will be required to restore this dam to a safe condition and original design life.

Inspection and Evaluation Methodology

The effectiveness, economics, and constructability of dam remediation designs for earthen dams begin and end with proper evaluations of the characteristics and seriousness of deficiencies as related to dam safety issues. ***<u>All</u> tree and woody vegetation growth on earthen dams is undesirable and has some level of detrimental impact upon operation, performance, and safety of an earthen dam***. However, not all tree and woody vegetation growth on earthen dams imposes the same level of impact on operation, performance, and dam safety. Dam owners, regulators, inspectors, and engineers must develop an understanding of the impact of tree and woody vegetation growth relative to location on the dam configuration. Proper evaluation of the seriousness of dam safety issues related to tree and woody vegetation growth on earthen dams is typically associated with the location of the undesirable plant growth on the dam embankment.

A few examples of the variability of seriousness of plant penetrations are presented herein to begin the learning process. The presence of a twelve-inch diameter tree on the downstream side of the crest of an earthen dam typically does not pose the same degree of impact on potential dam safety as a twelve-inch diameter tree located in the lower portion of the downstream slope. Conversely, a twelve-inch diameter tree in the upper portion of the downstream slope does not typically create the same level of seriousness as an unhealthy twelve-inch diameter tree on the upstream slope or front crest of a dam having a narrow crest width. Ornamental shrubs having shallow root systems along a wide roadway crossing the crest of an earthen dam will not impose the same level of seriousness as similar shallow rooted woody vegetation growing on the lower portion of the downstream slope.

The purpose of developing a well-defined inspection and evaluation methodology is to allow the establishment of dam remediation design priorities. Most anyone having a basic understanding of the seriousness of tree and woody vegetation growth to the safety of earthen dams can inspect an earthen dam and recommend removal of all trees, stumps, and root systems. However, inspectors and dam engineers must develop a definitive inspection and evaluation methodology in order to prioritize the seriousness of various locations of tree and woody vegetation growth on earthen dams.

Many individual dam owners do not have economic resources to undertake extensive dam remediation projects to bring an earthen dam into safe operation and performance conditions if the dam exists in a severely deteriorated condition. These owners often have to budget dam remediation projects over a scheduled maintenance and remediation construction period. Dam safety regulators, inspectors, and engineers that have developed and utilized a well-defined dam safety inspection and evaluation methodology can communicate priorities to dam owners so that the needed dam remediation design components can be completed in a prioritized manner. All too often dam safety regulators and engineers overwhelm dam owners with dam deficiencies without consideration of prioritization of deficiencies on dam safety, performance, and operation.

Dam Safety Inspection and Evaluation Zones

Five dam safety inspection and evaluation zones have been identified within the geometric configuration of a typical earthen dam. The delineated zones, illustrated in Figure 8, are not numbered in any implied order of seriousness relative to the impact of tree and woody vegetation growth, but have simply been numbered from upstream to downstream. The seriousness and potential impacts of tree and woody vegetation growth within each inspection and evaluation zone will be discussed during the description and identification of the delineated dam safety inspection and evaluation zones.

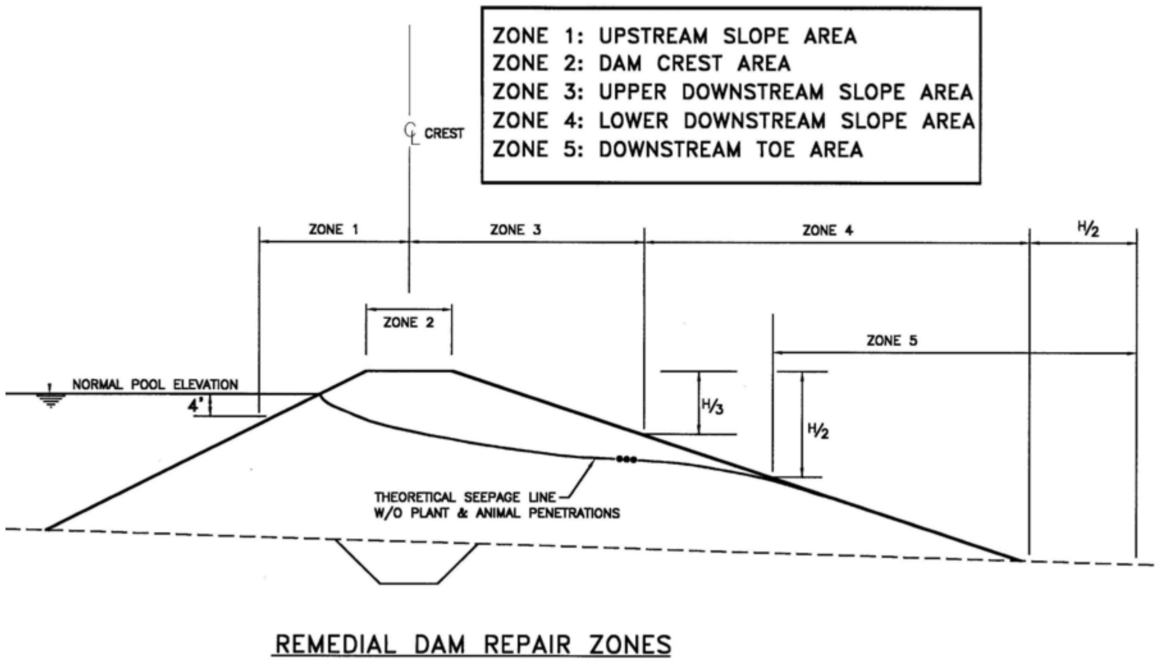


Figure 8

Inspection and Evaluation Zone 1 begins on the upstream slope of the earthen dam embankment at about four feet below normal pool elevation. Zone 1 extends laterally to the centerline of the crest of the dam. Tree and woody vegetation growth in Zone 1 is more critical relative to dam safety in the case of dams having a narrow crest width than those having a wide crest width. Zone 1 also includes the area subject to damage resulting from wave erosion and frequently recurring rapid drawdown events.

Inspection and Evaluation Zone 2 includes the entire width of the crest of the dam. Zone 2 overlaps Zone 1 by one-half the crest width. Overlapping a portion of Zone 1 with a portion of Zone 2 was done to emphasize the critical portions of both zones. Zone 2 is typically considered to be one of the least critical zones relative to dam safety issues associated with tree and woody vegetation growth. However, careful inspection of Zone 2 often reveals evidence of serious dam safety issues such as tension cracks, slope failure scarps, and erosion features that may or may not be related to tree and woody vegetation growth originating in other dam safety inspection and evaluation zones.

Inspection and Evaluation Zone 3 extends from the centerline of the crest of the dam to a point on the downstream embankment slope that is about one-third of the structural height below the crest of the dam. Zone 3 overlaps Zone 2 by one-half the crest width and is typically considered the least critical zone relative to dam safety issues associated with tree and woody vegetation growth. The seepage line and zone of saturation in this portion of an earthen dam embankment are typically sufficiently far below the surface to allow excavation of tree rootballs on the downstream slope of the dam without installation of a drain or filter system. A portion of Zone 2 has been overlapped by Zone 3 to draw attention to the most critical portion of Zone 3 that is the downstream portion of the crest of an earthen dam.

Inspection and Evaluation Zone 4 extends from a point on the downstream embankment slope that is about one-third the structural height of the embankment to the toe of the downstream embankment slope. Zone 4 is one of the two most critical zones relative to dam safety issues associated with tree and woody vegetation growth as well as other potential dam safety issues. This zone typically contains the interceptions of both the zone of saturation and the seepage line with the downstream slope. The close proximity of the zone of saturation and seepage line to the surface of the downstream embankment slope in this zone is a critical factor relative to dam safety issues associated with tree and woody vegetation growth. ***Tree and woody vegetation growth in this Zone 4 must be of major concern to everyone associated with the safety of an earthen dam and must be evaluated carefully relative to prioritization of dam remediation requirements.***

Inspection and Evaluation Zone 5 extends from the mid-height of the downstream embankment slope to a distance of one-half the structural height beyond the toe of the downstream embankment slope. This zone typically contains the interception of the seepage line with the downstream embankment slope and potential boiling (soil piping) action beyond the toe of the downstream embankment slope. As such, this zone is critical relative to long-term, steady-state seepage stability considerations for an earthen dam. Tree and woody vegetation growth in this zone rapidly develops into serious conditions that directly affect the safety of an earthen dam. Zone 5 overlaps Zone 4 to draw attention to the more critical portions of both Zone 4 and Zone 5. As in the case of Zone 4, Zone 5 is typically considered to be one of the two most critical zones relative to dam safety issues associated with tree and woody vegetation growth. Tree and woody vegetation growth in Zone 5 must be a concern to all involved in the safety of an earthen dam. ***Maintenance and/or engineered dam remediation must be undertaken immediately in the event that tree and woody vegetation growth is significant within Zone 5.*** Control of tree and woody vegetation growth well beyond the toe of the downstream embankment slope cannot be over-emphasized. This area of an earthen dam is critical to overall stability and potential dam safety issues associated with embankment and foundation seepage.

The dam safety inspection and evaluation methodology set forth herein can be easily modified and/or extended to meet the needs of specific dam owners, dam safety regulators and inspectors, and engineers. This proposed methodology for dam safety inspections and evaluations should provide a basic plan that will allow the reader to customize and/or improve existing dam safety inspection and evaluation programs.

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Chapter 5
Controlling Trees and Woody Vegetation on Earthen Dams

The establishment and control of proper vegetation on an earthen dam are essential to maintaining a *safe* dam. Effective, shallow-rooted, vegetative cover is necessary to reduce and prevent embankment slope erosion. Trees and other undesirable deep-rooted vegetation should be prevented from being established for the following reasons:

- Permit effective inspection and monitoring of embankment crest and faces
- Allow for adequate access to dam for normal and emergency operation
- Prevent structural damage from embankment piping and internal erosion, unstable slopes from toppled trees, concrete wall/slab joint cracking/displacement, and other problems
- Reduce possibility of root-blocked drains
- Prevent blockage of spillway channel
- Discourage rodent and other animal activity by eliminating food source and habitat
- Eliminate expensive tree and brush removal and remediation costs
- Reduce impression of owner neglect

Consequently, dam owners should observe these four important rules:

1. Existing trees should be removed and not be allowed to mature on earthen dams, abutment groins, or around water conveyance structures
2. Trees or shrubbery should never be planted on or around new or existing dams
3. Existing trees should be watched closely until they are removed
4. Grasses and shallow-rooted native vegetation are the most desirable surface covering for an earthen dam.

Dam owners should be especially aware of dangerous or potentially hazardous tree conditions such as decaying or dead branches; lightening-caused splits; stripping or breakage; leaning, uprooted or blown-down trees; and seepage around exposed tree roots located along embankment slopes, especially in vulnerable downstream toe or abutment areas. Outward leaning trees may result from a slumping embankment condition that can be an indicator of slope instability. Any of these conditions warrants immediate attention by the owner and a qualified engineer.

Woody vegetation and tree growth creating undesirable root penetrations in earthen dams can be controlled or prevented by proper management of root growth into new dams and dams that have previously been cleared of trees by proper removal procedures. In this manual, some of the characteristics of woody vegetation and tree growth are presented relative to the aging of an earthen dam. Remedial dam repair design procedures and construction techniques are presented for proper removal of trees of various sizes in various areas of the geometric configuration of an earthen dam. Proper management and control of woody vegetation on new and previously repaired dams (tree removal projects) are based upon an understanding of soil conditions that limit root growth, factors that affect or promote root growth, and various procedures and techniques that can be used to stop, redirect, and/or reduce the rate of root elongation.

The purpose of this chapter is to provide a basic understanding of requirements for healthy root elongation, and to provide an introduction to some techniques and procedures that can be utilized to manage and control undesirable woody vegetation and tree growth on earthen dams. Development of a basic level of tree-literacy combines basic understanding of soil properties and characteristics with basic understanding of requirements and characteristics of healthy tree root elongation and tree growth into a single conceptual understanding of management and control.

Healthy Tree Growth Requirements

The primary requirement for healthy tree growth is an environment for continual elongation of tree roots. Continual elongation of tree roots is essential to healthy tree growth for the following reasons: 1) respiration that requires a continual flow of oxygen to root tissue through soil pores; 2) soil moisture uptake that requires continual availability of soil pore water that can be captured by root tissue; 3) nutrition that requires root systems to make continuously renewed soil/root surface contact to provide needed elements and nutrients for healthy tree growth; and 4) support and stabilization that requires soil-to-root surface contact to resist externally applied loads.

Managed tree root growth control is required to prevent or minimize dangerous impacts on dams. To constrain root growth, identification of soil attributes and it's supporting environment that promote or limit growth is required. By understanding what soil conditions limit growth, various tools and techniques can be used to stop, redirect, or inhibit tree root growth and elongation. The following discussion on root growth requirements, limitations and mechanics is based on a series of publications authored and furnished by Dr. Kim Coder of the University of Georgia Cooperative Extension Services (Coder, FOR98-9, -10, -11, & -13, 1998). The reader is referred to these well-referenced publications for further and more detailed information.

Trees are not much different from all living organisms, relative to biological needs. Trees must have (1) oxygen gained through respiration, (2) water gained through adsorption and absorption, and (3) nutrition gained through adsorption and absorption, and (4) a stable foundation to withstand external forces. General root growth resource requirements are summarized in Table 1. Roots utilize soil spaces for access to water and essential element resources, and soil mass to provide structural support. Soil minerals surround the water-filled and air-filled voids or pores. These pores are continually filling and draining with water and air, depending upon the availability of water, water uptake, and atmospheric air. Root growth follows pathways of interconnected soil voids. Such voids result because of space between soil particles, between soil structural units (i.e., blocks, plates, aggregated soil, etc.); along soil fracture lines, lenses, joints, and various interstitial interfaces; and through paths of biological origins such as decayed or shrunken roots, animal burrows, etc. Better means of controlling growth can be developed by understanding resource levels that encourage and limit root growth (Coder, FOR98-9, 1998).

Root Resource	Requirements	
	Minimal	Maximum
Oxygen in soil atmosphere	2.5%	21%
Air pore space in soil (for root growth)	12%	-
Soil bulk density restricting root growth	-	1.4 g/cc (clay) (note: 1 g/cc = 62.4 pcf)
	-	1.8 g/cc (sand)
Penetration strength (water content dependent)	0.01 kPa (note: 1 kPa = 1kN/m^2 = 10 mbar = 0.145 psi)	3 MPa
Water content in soil	12%	21%
Root initiation (O_2% in soil atmosphere)	12%	21%
Root growth (O_2% in soil atmosphere)	5%	21%
Progressive loss of element absorption in roots (O_2% in soil atmosphere)	15%	21%
Temperature limits for root growth	40°F/4°C	94°F/34°C
PH of soil (wet test)	pH 3.5 (acidic soils)	pH 8.2 (alk. soils)

Table 1. General list of tree root growth resource requirements (After Coder, FOR98-9, 1998).

Roots survive and proliferate where adequate water is available, temperatures are warm, oxygen is present and other essential resources are concentrated. They generally tend to be shallow, limited by available oxygen and water saturation in deeper soil. However, near the base of the tree, deep-growing roots can be found, but are aerated by soil fissures and cracks and around roots where mechanical forces exerted by wind loads on the tree loosen the soil.

The ability of primary root tips to enter soil pores, open soil pores and elongate through pores is dependent upon the force generated by the root and the soil penetration resistance. As the diameter and length of an expanding root increase, its strength to resist structural failure and its expansive force it can generate both increase. The chance for structural failure increases with longer and smaller diameter roots, while short and thick roots generate significant force but minimize structural failure. Radial expansion of the root structure immediately behind the tip also helps to fracture or reduce penetration resistance in the soil ahead of the elongating root tip.

Roots use the mass of the tissues behind the tip, including root hairs, lateral root formation, and microbial entanglements to minimize the length over which root elongation force (or pressure) is expressed, thus reducing structural failure potential. As the root elongates, only root tissue within about six root diameters behind the tip is involved with force generation. Root tissue further back will act as an anchor and support base against the soil. Root tip pressure can be enormous and can range up to 9-15 MPa (9,000-15,000 mbars, 130-215 psi, or 18,700 – 31,000 psf)), with 1MPa or about 15 psi being most cited. Thus a typical root tip diameter of one millimeter is capable of generating up to about a 0.25-pound force. While tree roots cannot produce enough pressure to penetrate concrete, pipes, and most plastics or metals, they do take advantage of cracks, holes, joints and faults already in materials and exacerbate cracks and faults by growing root mass within, beneath, or around materials. When water supply is short, or when temperatures increase, diameter of roots are sacrificed to facilitate more elongation. Roots can lose more than one-third of their diameter under dry conditions, leaving roots thinner and elongating at a slower rate. Such conditions can generate passageways and set up the possibility for piping and internal erosion conditions in an earthen dam. Additionally, the loss of root contact with the soil and potential for mechanical failure of the elongating root system can lead to poor tree support, thus making a tree vulnerable to wind forces and possible upending. Tree roots are opportunistic in the colonization and control of resource space. The attributes that make a root an ideal resource gatherer for the tree conspire to make roots soil matrix explorers and fault exploiters. To prevent, control or eliminate roots from the soil infrastructure, dam owners and dam design engineers need an understanding of environmental conditions that limit and promote root growth. The foregoing discussion is summarized in terms of the four main requirements and conditions for tree growth and tree root development as follows:

Trees need to breathe. Oxygen is required for healthy tree growth through continual root elongation. In order for proper root respiration to occur, oxygen must continually move through soil pore spaces to the root tissue. Tree roots are not the only living things in the soil pore system that is competing for oxygen. As oxygen flows toward an otherwise healthy root system, enormous numbers of aerobic organisms can utilize portions, and perhaps all, of the available soil pore space oxygen before it can be utilized by root systems. If all of the oxygen is used before reaching the root system, changes must occur in the characteristics and growth rate of the root system. Trees have the ability to generate energy for short periods using carbohydrates in low or non-oxygen environments. However, this process is taxing on tree growth, and is approximately twenty times more inefficient than under normal oxygen availability and respiration conditions (Rendig & Taylor, 1989; Coder, FOR98-10,1998). Air-filled voids in soil must be of sufficient size and continuity to allow carbon dioxide to move away from the root system and oxygen to move to the root system in order to sustain healthy root elongation and tree growth. Water-filled voids resulting from saturated soils around roots inhibit this process at a rate 10,000 times less than air-filled voids (Rendig & Taylor, 1989; Coder, FOR98-10, 1998). When oxygen drops below two to five percent of atmospheric content, root growth and the root's ability to generate elongation force significantly declines (Souty & Stepniewshi, 1988). Table 2 summarizes air void content requirements of various soil texture and types that limit root elongation. The table data shows that, for most embankment soils, trees need at least 10-25% air-filled voids in order to promote healthy growth. In summary, ***Roots that cannot breath die, resulting in unhealthy, unstable, and/or dead trees.***

Soil Texture	Root-limiting % pores normally filled with air
Sand	24%
Fine sand	21
Sandy loam	19
Fine sandy loam	15
Loam	14
Silt loam	17
Clay loam	11
Clay	13

Table 2. Root growth limiting air-pore space values by soil texture (After Coder, FOR98-10, 1998)

Trees need to drink. Second behind the need for oxygen is a tree's requirement for water. Water uptake of trees occurs both by adsorption and absorption. In the same manner as that described for oxygen supply, tree root systems depend upon the flow of soil pore water to the root system to continually uptake sufficient water to sustain healthy root elongation and tree growth. Soil voids that are sufficiently small to prevent continual flow of pore water can limit the amount of water that elongating roots can use within the soil matrix. Often, the moisture uptake is typically lower than that required for root elongation and healthy tree growth. As noted in Table 1, root elongation and healthy tree growth cannot be sustained where average soil moisture contents are less than about 12 percent nor greater than about 40 percent. ***Soils that restrict free moisture movement preclude healthy root elongation (penetration) and healthy tree growth. Compacted soils limit pore space and therefore tend to limit supplies of both oxygen and usable water to trees.***

Trees need nourishment. Third, roots systems must provide nutrition for healthy root elongation and tree growth. Root elongation is required to encounter needed minerals, nutrients, and companion microorganisms in the soil mass. Root elongation must be continuous since replenishment of nutrients in soil is a long-term process that will not meet the requirements of stationary root systems and trees. Elongating or growing root systems continually encounter soil pores of various sizes. Soil pores that are larger than root tips create little resistance to root elongation; however, as soil pore sizes approach the size of root tips and/or become smaller than root tips resistance to root elongation increases significantly. Soil pores that are much smaller than root tips may be deformed in weak or soft soils; however, these small soil voids will reject root penetration in dense or strong soil masses. Roots cannot 'squeeze' into small, rigid soil pores within soil masses where soil strength and density preclude soil deformation and, therefore, growth is inhibited. ***High strength, dense soil masses containing limited required nutrients for healthy root elongation will not sustain healthy tree growth.***

Trees need foundation support. Tree stabilization and support is provided by both components of the tree root system. The root plate (root ball) provides vertical support for the weight of the tree much the same as a shallow foundation system provides support for a building column. However, tree root systems must also resist laterally applied external loads (i.e., wind loads). Lateral root systems provide required lateral support capacity against horizontal forces through development of soil-to-root frictional forces (nature's own application of "soil nailing"). Inadequate root elongation results in reduction of base and lateral support, resulting in an unstable tree that becomes unhealthy and/or subject to failure under laterally applied loads. ***Dense, compacted soil masses preclude proper lateral root elongation thus creating unstable, unhealthy trees that are subject to premature failure.***

In summary, whether in design of new dams or in maintenance of older existing dams, engineers and dam owners need to appreciate the forces, conditions and resources that control and affect the health and stability of trees so as to prevent or discourage trees from growing on new or re-constructed dams or to understand why/how trees respond to given and changing conditions on existing earthen dams.

Tree Root Elongation Management and Control

There are at least eight well-documented methods and tools available to control and limit tree (root) growth through the application of tree root elongation processes, resource availabilities, and soil preparation characteristics. These methods take advantage of depriving the tree roots of ideal resource needs for healthy growth discussed above. While these methods have been primarily used in urban or agricultural applications and settings, some methods are directly applicable to use on earthen dams and include the following methods described by Coder (FOR98-11):

1. **Intelligent designs** and applications that include techniques and materials based upon knowledge of tree growth and root development requirements. Here, minimizing available soil material faults or interfaces and tree root spaces are the preferred means for controlling and discouraging tree growth with the philosophy 'Build it correctly and they will <u>not</u> come!'

2. **Root kill zones** utilizing cultivation methods, sawing and cutting, trenching, vibratory plows, and chemicals to control, discourage, and remove root structure. However, these methods often result in damaging or killing the tree that, perhaps, should have been removed in the first place.

3. **Root exclusion zones** utilizing soil structure changes, soil compaction, water/aeration, stress, anaerobic conditions, soil injections and slurries, soil additives, and chemicals to prevent roots from colonizing the soil structure areas due to applied physical or chemical changes to the soil. Changing the soil structure, pore space volume or drainage/aeration matrices can generate a soil environment that roots cannot effectively grow and sustain. A variety of physical- or chemical-based soil altering materials (i.e., soil injected clay slurry or cement solutions) can be effective, at least over the short term if adequate soil volume is treated. Compacting soils appear to be a very good way to prevent root colonization. High density soils increase the resisting strength of these soils to root penetration and deprive the roots from needed oxygen and available water. Certain types of clay soils, freeze-thaw cycles, biological activity, and poor soil compaction can, over time, produce root-accessible pore space. Soil or infrastructure building material additives that neutralize or sterilize the available minerals and nutrients such as nitrogen gas, sulphur, sodium, zinc, borate, salts, or herbicides may produce serious environmental consequences, short-lived results, and non-targeted damage potential. Other methods or additives may be cost-prohibitive. See Figure 6 at end of chapter for root clearance zones.

4. **Air gap systems** designed to provide temporary and permanent air spaces for root pruning and lack of root support by use of large cobble stone barriers and drain systems. One of the more effective means of controlling tree root growth is providing stone matrices that dry quickly, create large air gaps, have poor water-holding ability, and are impermeable to systematic root penetration. Gravel layers or areas having at least 3/4 inch stone size or clean, graded, medium-sized rubble (crushed brick remnants or recycled paving and other materials), provided it is not covered or filled in with sand, are reported to produce large enough air gaps to discourage root growth.

5. **Barrier systems** using commercial root traps, root deflectors, containment devices, metals, screens, plastics, paints, and inhibitors. One of the easiest and most available materials used to control root growth are various types of 2D-type screens and barriers. While some barriers are not completely effective, many types have been shown to be effective. A list of mechanical, biological and chemical tree root growth control barriers, products and systems is shown in Table 3.

a. Copper sulfate-soaked, synthetic, non-woven fabric
b. Copper screen
c. Cupric Carbonate ($CuCO_3$) in latex paint
d. Fiberglass and plastic panels
e. Fiber-welded geosynthetic fabric/mesh
f. Galvanized metal screen
g. Ground-contact preserved plywood
h. *Geomembranes and heavy rigid plastics
i. Infrastructure aprons and footings
j. Metal roofing sheets
k. Multiple layers of thin plastic sheets
l. Nylon fabric/screen
m. Permeable woven geosynthetics
n. Rock-impregnated tar paper/felt
o. *Slow-release chemical barriers
p. Thin layered bitumen & herbicide mixtures
q. Woven and non-woven slit-film plastic sheets

*Common commercial tree growth control products available

Table 3. Selected list of tree root growth control barriers (after Coder, FOR98-11, 1998)

The costs of these products will likely continue to decrease as the demand for these products increases in the future. Of the barriers shown in the list, three types are most commonly used: traps (root engaging and constricting), deflectors (walls), and inhibitors (chemical constraints). Combined features of the barrier, the site, and barrier installation and maintenance are critical to their effectiveness, but no barrier should be assumed to stop all roots under all conditions. Most types of mechanical and chemical barriers have limited effectiveness lives and this should be factored into any long-term cost analysis. The reader is directed to the Table 3 reference source and other related publications for details on commercially-available root barriers.

6. **Directed growth systems** to concentrate roots in desired directions, guide root growth along channels, allow root survival in desired areas, and create root culverts or layers. As noted earlier, roots are opportunistic and grow and proliferate where there are good supplies of resources. Understanding root elongation, colonization, and survival processes allows growth-favoring soil layers, corridors, and areas to be designed for directing or deflecting roots away from infrastructures where tree roots can be harmful. Several methods or systems are used to attract, deflect, channel or lead roots in a direction or area as needed. One attraction method used is called "baiting" and involves providing ideal essential soil condition resources in a direction away from an infrastructure. The net result is a much higher survival and growth rate in that part of the root system as opposed near infrastructures where root damage can occur. Water, growth nourishment elements, and oxygen should be limited and compaction should be maximum near infrastructures.

   Another method is to "shepherd" roots to desirable locations using trenches, channels, layers, raceways, tunnels, and other devices that are surrounded by root control obstacles, barriers, or resource constraints. Growth channels filled with rich, well-aerated, ecologically healthy growth medium will encourage root colonization and survival in areas away from sensitive infrastructure targets.

7. **Selection of desired species** of trees that require lower soil oxygen environments, have improved root morphology, and are more effective species for long-term solutions. This method focuses on choosing and planting available tree species that can survive under rather limited or harsh environmental conditions. Several tree species are available that are small in size, have shallow and less aggressive rooting, and are slower growing. Dam owners, however, should be reminded again that trees in general are not a good plant option and have no place on dams; instead, more desirable, native grasses should be planted and maintained.

8. **Creating avoidance zones** to separate tree growth from earthen dam embankments and dam appurtenances where root damage may be critical thus establishing biological-free zones that reduce potential problems. This method simply recognizes that there are places where trees are acceptable and other places, namely dams, where they are not (see Figure 6).

The most practicable of these methods for use on earthen dams are those associated with intelligent design development, exclusion zones, kill zones, and barriers. Within this group of suitable methods the combination of intelligent design development and exclusion zones are the most effective. With an understanding of the previous meshing of soil properties with healthy tree root elongation, it is not difficult to develop an intelligent design scheme for new dams and the remedial repair of existing dams. An intelligent design philosophy associated with dam embankment design and construction would involve proper embankment soil compaction as the means of exclusion of root elongation.

In summary, there are many tools, methods and options for minimizing or preventing tree root-caused damage to earthen dams. The most important management (and design) concept to understand is how tree roots are invited to be associated with interstitial elements and colonize soil matrices and discontinuities, and resource availability areas. Our responsibilities as owners and dam design engineers must lie with creating and using any or a combination of the numerous root growth control tools and techniques that are tree-literate so that trees do not have the opportunity to become a safety problem to embankment dams and their appurtenances in the first place.

Exclusion by Embankment Compaction

Design and construction practices of using optimum compaction of embankment soils reduce potential settlement of embankments, increases shear strength of the embankment soils, decreases the permeability of the embankment soils, and minimizes long-term changes in the physical and engineering properties of soils. When embankment soil compaction results in the attainment of desirable objectives from a geotechnical engineering behavior perspective of earthen slopes, compaction of embankment soils also precludes tree root growth and elongation as a result of exclusion of most of the requirements for healthy root elongation and tree growth. As has been previously noted, densely compacted soils discourage root elongation through increased resistance, lowered oxygen levels, and reduced available water. Traditional embankment soil compaction specifications require that the soil be compacted to about 95 to 98 percent of the standard Proctor maximum dry density as determined by ASTM D-698. Furthermore, most properly written soil compaction specifications generally require that compaction moisture contents be maintained about two percent below to three percent above optimum moisture content. At these degrees of compaction and at these moisture contents, soil oxygen content, water content, and soil pore size are not available for healthy root elongation and tree growth. Even if there is sufficient moisture content in the soil to otherwise sustain healthy root elongation, the soil pore sizes are so small that available pore water cannot be effectively moved to the root system. Consequently, the compacted dam embankment fill soil produces an exclusion system that mechanically impedes healthy root elongation and tree growth. Table 2 provides a summary of minimum air voids for various soil types required to impede root elongation for healthy root and tree growth.

Maintenance Mowing and Kill Zones

The second most effective method of controlling woody vegetation and tree growth on dam embankments is through the use of native grass or ground cover with maintenance mowing, and using kill zones where necessary around critical structures to control trees and other undesirable nuisance-types of vegetative growth. Maintenance mowing should be done ***at least*** twice per year with one mowing scheduled for spring after initiation of new spring growth and the second mowing scheduled for late fall immediately prior to the first killing frost or freeze (See Chapter 7). The spring mowing should be a very close cutting of all vegetation to allow maximum sunlight to penetrate to desirable grass cover species. The fall cutting should not be as close as the spring cutting to provide maximum resistance to surface runoff erosion and to provide cover for desired wildlife species (quail, rabbit, grouse, songbirds, etc.).

In areas where regular maintenance mowing is not practical to control woody vegetation and tree growth, the selective use of herbicides might become necessary to control small woody vegetation and tree growth. There are many commercially available herbicides that are environmentally safe to use in most applications. However, one must always be careful in the use, or overuse of herbicides, because they are design to kill and/or impede (slow) plant growth. Overuse of herbicides may contaminate areas of the dam embankment to such an extent that desirable grass cover cannot be effectively grown. One must always follow manufacturers recommendations when using herbicides, or better yet, solicit the advice of the nearest USDA/NRCS agent prior to using herbicides to control woody vegetation and tree growth on earthen dams.

Chemical Barrier Systems to Inhibit Root Growth

Commercially available barrier systems are effective in controlling root elongation and growth; however, many of these barrier systems are relatively expensive and cannot be justified for placement over the entire earthen dam embankment. These barrier systems are often economical for placement on portions of earthen dams where accessibility is difficult after construction and/or where particularly problematic and nuisance woody vegetation and tree growth is likely to occur.

One typical biocide product, called “Biobarrier©” is marketed and promoted, among other applications such as sidewalk and landfill cap protection, to prevent tree and plant roots from penetrating dams. The product consists of long-term, slow release nodules containing Trifluralin herbicide, that are bonded to a geotextile fabric as shown in Figure1.

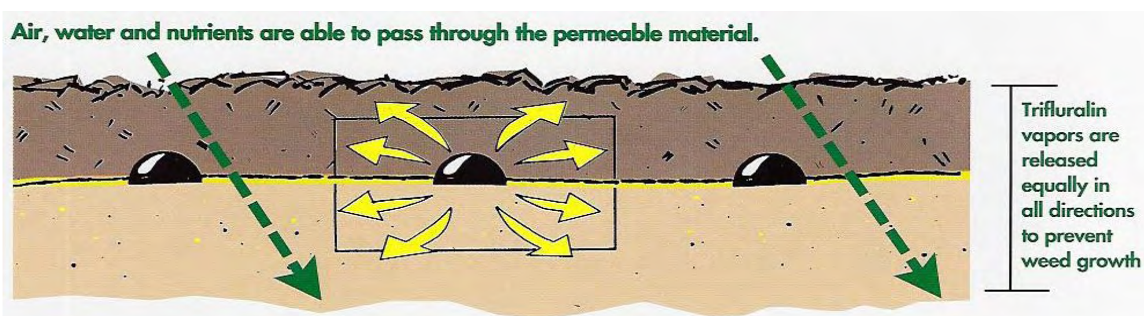


Figure 1. Chemical biocide barrier installation showing slow-releasing biocide nodules attached in a woven fabric matrix and installed under a cover of soil, mulch, gravel or stone (Biobarrier©).

This particular barrier is environmentally acceptable to EPA and indicated to be effective against all types of roots around pipes, hardscapes, and dams and levees. While the product is guaranteed for 15 years, its life is inversely proportional to environmental temperature conditions.

For example, its effectiveness is expected to be about 40 years at 20°C (68°F) and about 100 years at 15°C (60°F). For deep soil cover, it is expected to last 100 years; for near soil-surface weed control installations, where temperatures are higher and cycle daily, the projected life is expected to exceed the guaranteed 15-year life. Figures 2 and 3 show an application of this product on a 25-foot high and 350-foot long earthen dam to prevent deep penetration of deep-rooting native trees and woody vegetation such as willows, sagebrush, and chokecherries.

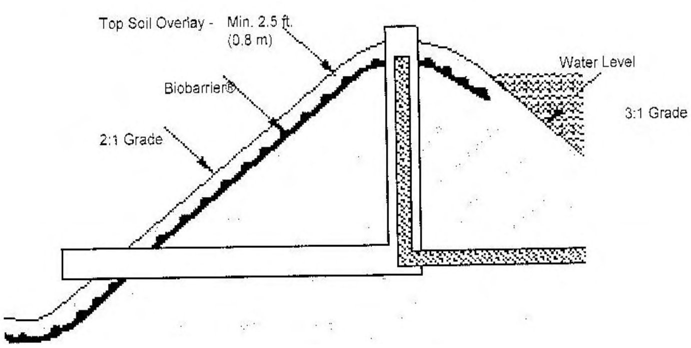


Figure 2. Earth dam installation of chemical

Figure 3. Installed chemical barrier on a dam in Montana (Kershner, 1992)

Herbicidal Applications

Herbicidal delivery to control undesirable vegetation depends on several considerations which include (a) types of plants and weeds (herbaceous, vines, trees, brush, phreatophytes, etc.), (b) site conditions (geology/sinkholes/karst), topography, (c) proximity to water bodies, (d) riparian land use, (e) sensitive environmental factors (Federal, state & local regulations; potential off-site wind drift over water or land), and (f) application factors (dosage, placement, retention time, plant growth stage, physiological factors, and method of application). A very important consideration is for the user to follow the herbicide manufacturer's warnings and instructions. The user is also encouraged to consult with a local county extension office or agent to obtain advice on the best and safest herbicide to use and on what recommended application technique to use. While there are several herbicidal delivery methods available, the most common techniques are shown below in Figure 4.

- Foliage spraying
- Tree injection
- Frill or girdle treatment (slash through bark then spray or paint)
- Basal bark spraying
- Cutting tree and poisoning stump
- Soil treatment
- Other

Figure 4. Herbicide delivery application methods

Some of these techniques and herbicides used are illustrated in Figures 5a – 5f. The U. S. Department of Agriculture (SCS, now NRCS) published a useful methods, treatment points, and time of treatment guidelines for controlling trees and brush on dams, including some of the applications listed in Figure 4 (USDA, 1988). Table 4 summarizes the USDA recommendations. With the exception of Krenite, which is applied to the foliage, 2,4-D is the only approved herbicide for poisoning trees on dams. 2, 4-D is manufactured by several companies and is sold under several trade names. In all cases, the user is cautioned again to follow the manufacturer's instructions and should consider the manufacturer's label instructions to supercede recommended instructions in the USDA table.

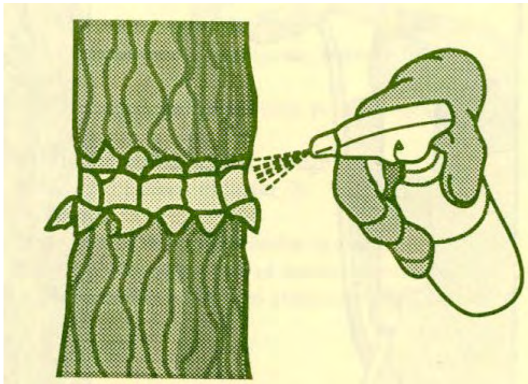


Figure 5a. Frill cut application.

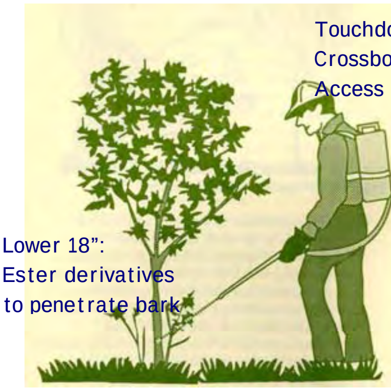


Figure 5b. Basal bark spraying.

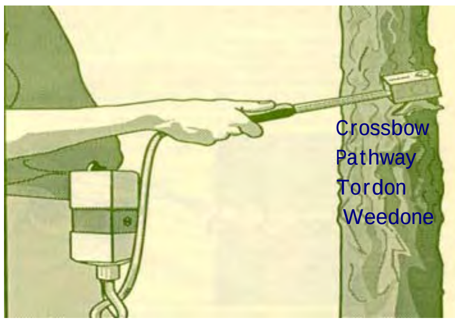


Figure 5c. Hypohachet application.

Figure 5d. Cut-stump application.

Figure 5e. Backpack foliar application on dam.

Figure 5. Applications and techniques for different herbicidal deliveries to trees and brush, with example commercially-available herbicides listed.

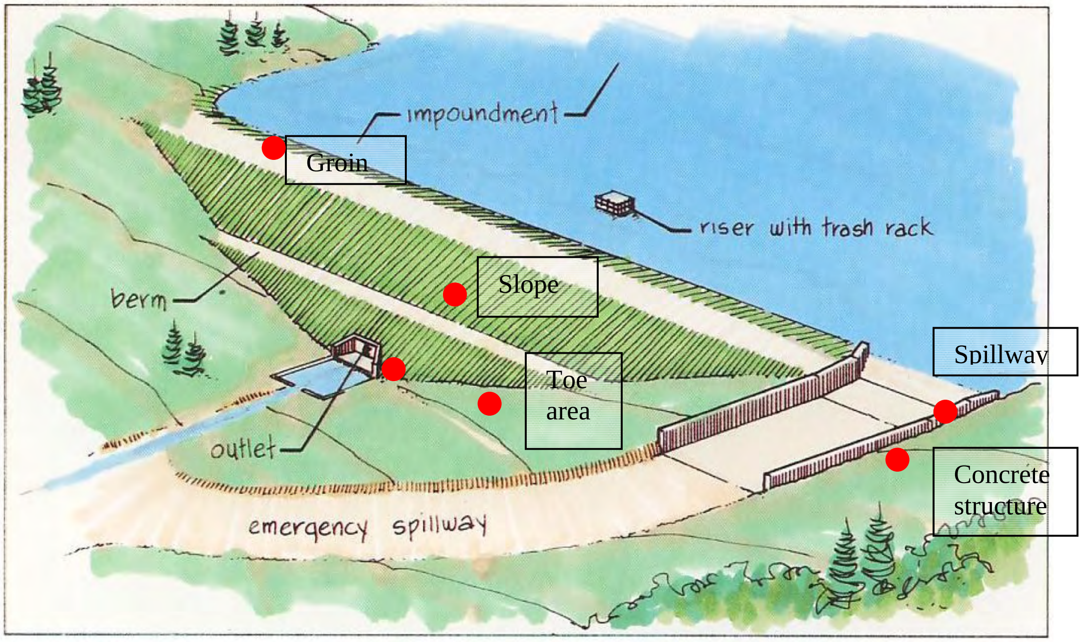
Figure 5f. Tractor spraying application on dam.

Method of Application	Recommended Time
• Cutting trees and poisoning stumps • Injection • Foliage spraying • Frill treatment (trees larger than 4” dbh) • Basal spraying (trees smaller than 6” dbh) • Prescribed burning (trees smaller than 2” dbh)	• Growing season • Anytime • Last two (2) months of growing season • Anytime • Growing season • See technical specifications

Table 4. Recommended methods and time of herbicide treatment application (USDA, 1988).

USDA recommends that trees killed by herbicide should be removed within the year following treatment to prevent front slope from falling into the reservoir and plugging the spillway. Downed trees on the back slope should also be removed to prevent potential problems of seepage, erosion, burrowing animals, etc.

The reader is referred to the USDA guideline for detailed discussion on each of the six treatment methods listed in the above table. These methods can be applied to establish tree and woody plant clearance or avoidance zones on and around dams as illustrated in Figure 6.



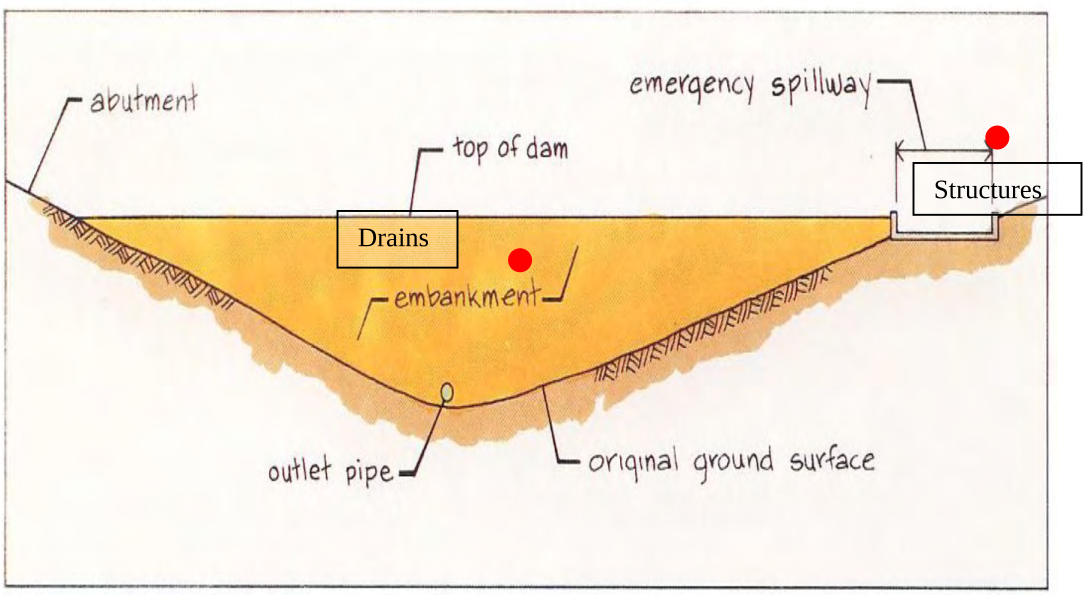


Figure 6. Tree clearance zones for embankment dams and dikes.

Desert Plants

Deep-rooted desert plants, when left unchecked, can propagate rapidly on earthen dams located in arid and semi-arid regions of the U. S. Some of these deep-rooted plants include Desert Broom shown in Figure 7, Salt Cedar, Mesquite, Cypress, Cottonwood and Paloverde. All of these species require considerable effort to control and should not be allowed to become established anywhere on dams. Palm trees can be a problem in that they are shallow-rooted, but develop a large root ball that can produce large cavities when toppled during high winds. Upstream and downstream access roads, in place at many dams, should be utilized to create a buffer zone between these species and the toe of dams.

Figure 7. Deep-rooting Desert Broom Plant

The Maricopa County, Arizona, Flood Control District (MCFCD) recommends, in cases where deep-rooted plants are two feet in height or less, that they be controlled with a 3-5% solution of Roundup® Pro (Renckly and Drake, 1999). If the plants are over two feet in height they should be hand cut to ground level. The stumps should be treated within the first five minutes by an almost straight mix of either Roundup Pro® or Garlon 3A-Garlon 4®, depending on the temperature conditions. MCFCD recommends that when treating Salt Cedar near waterways that Rodeo be sprayed at a 3-5% solution with six ounces of Siltwet® per acre added. This is sprayed on plants two feet in height and under. Plants over two feet are hand cut and the stump treated with an almost straight solution of Rodeo® within five minutes of cutting the plant.

Revegetation on earthen dams is recommended to minimize erosion on the embankment slopes and to provide natural landscaping for earthen dams. MCFCD recommends hydro-seeding over labor-intensive hand-seeding to revegetate dam embankments. Figure 8 illustrates hydro-seeding operations on a floodway dam. Seed, water, tack material and a wood fiber or paper mulch are mixed in a hydro-seeder and sprayed directed onto the slopes. The seeds are encapsulated in the mulch and tack material until enough moisture is present to begin the germination process.

Figure 8. Hydro-seeding operations on a floodway dam in Maricopa County, Arizona (Renckly & Drake, 1999).

MCFCD has found that it takes 2 to 3 years before "significant" vegetative cover results are achieved because of the arid climate and high degree of embankment compaction. MCFCD determines the desirable seed mix by first laying out a test acre on the dam embankment and a plant count is then taken of all the different plant species that are native to the area and placed on the test acre. This plant count is converted by the seed supplier into the amount of seed needed to germinate the desired amount of the species per acre. The amount of pure live seed (PLS) applied for individual plant species also varies by availability from the local seed supplier. Table 4 shows a seeding mixture specified for one of the District's dams and is typical of specified hydro-seeding mixes. No deep-rooted species are allowed in the seed mix.

MCFCD has found that revegetation efforts have successfully reduced erosion problems, but has attracted both desirable and undesirable animals.

SEEDING MIXTURE

Common name	Scientific Name	Pounds of Seed Per Acre
Purple three-awn	Aristida purpurea	4
Indian Wheat	Plantago insularis	3
Needle Grama	Bouteloua arstiodoides	1
Desert Marigold	Baileya multiradiata	1
Mexican Gold Poppy	Eschschotzia mexicana	1
Creosote	Larrea tridentata	8
Brittle Bush	Encelia farinosa	2.5
Bursage	Ambrosia deltoidea	2

** **Note: Apply 1500 pounds of wood fiber mulch in Hydro-seed mix, plus 150 – 200 pounds tack material per acre.**

Table 4. Typical seed list specified for a flood control dam managed by the Maricopa County, Arizona, Flood Control District (Renckly & Drake, 1999)

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18. Univ. of Tenn. Agr. Extn . Serv., G. Rhodes & G. Breeden, 2001 Weed Control Manual for Tennessee, Bulletin PB-1580, December 2000.

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Chapter 6
Dam Remediation Design Considerations

Specific dam remediation design considerations, procedures, and techniques will be considered for each of the previously identified dam safety inspection and evaluation zones. Figure 1 presents these zones as a review prior to discussion of potential dam remediation design considerations for each zone. Dam remediation design alternatives presented herein should be considered examples. These remediation design examples should not be considered the only alternatives for use in dam remediation design to correct deficiencies associated with tree and woody vegetation growth on earthen dams. Some additional dam remediation design alternatives presented for correction of tree and woody vegetation growth related deficiencies also provide positive correction of other deficiencies and protection against other types of earthen dam deterioration.

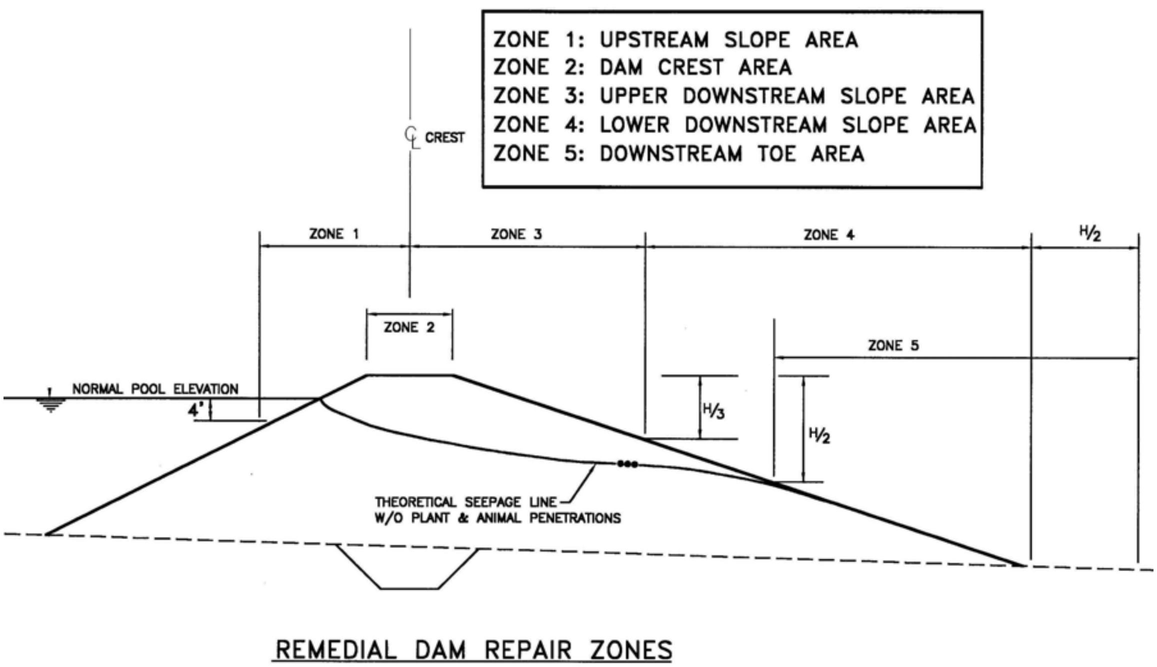

Figure 1

Inspection and Evaluation Zone 1

Figure 2 illustrates potential problems that can occur in Zone 1 with respect to tree and woody vegetation growth on earthen dams. This illustration also depicts the occurrence of wave erosion, vehicle access, and surface runoff erosion. Potential problems illustrated include instability of relatively large trees on the upstream slope and dam crest, and alteration of the seepage line as a result of wave erosion.

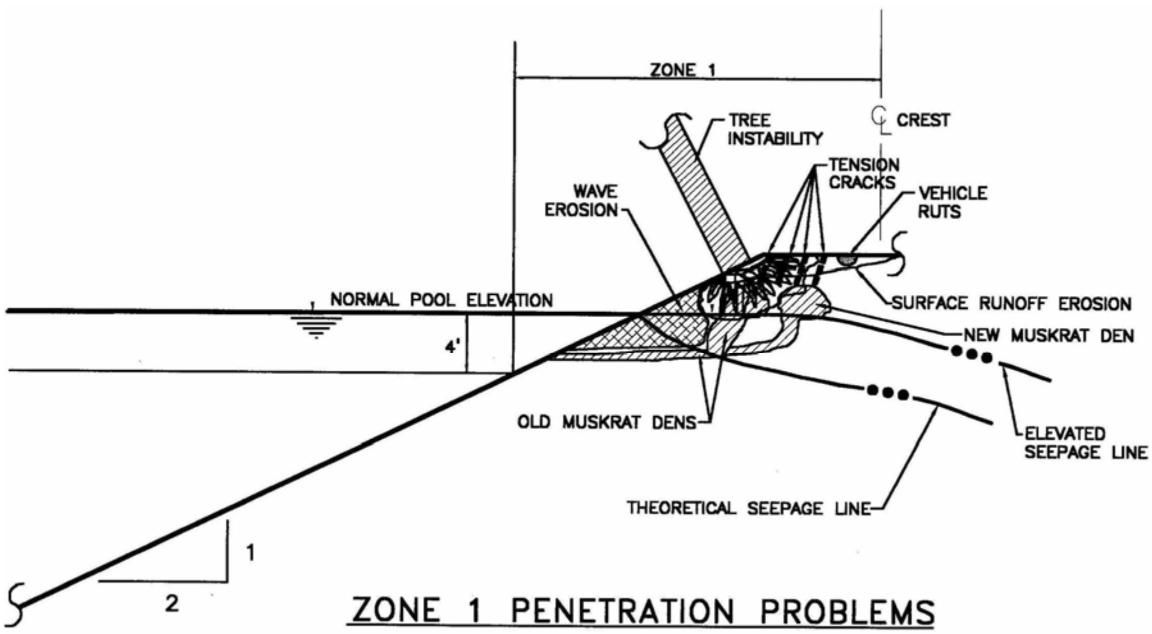

Figure 2

Dam remediation design techniques necessary to address potential problems illustrated in Figure 2 are illustrated in Figures 3 and 4. Dam remediation construction typically requires lowering of the normal pool elevation and/or complete drawdown of the retained reservoir. This is particularly true for dam remediation construction in Zone 1. The normal pool elevation should be lowered as far ahead of the scheduled dam remediation construction as practicable.

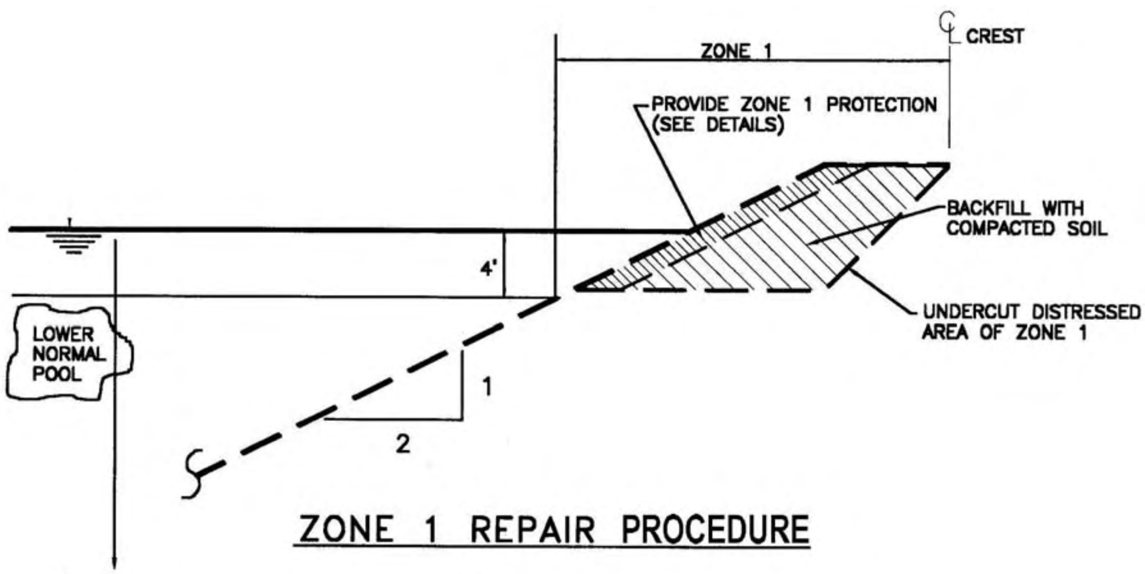

Figure 3

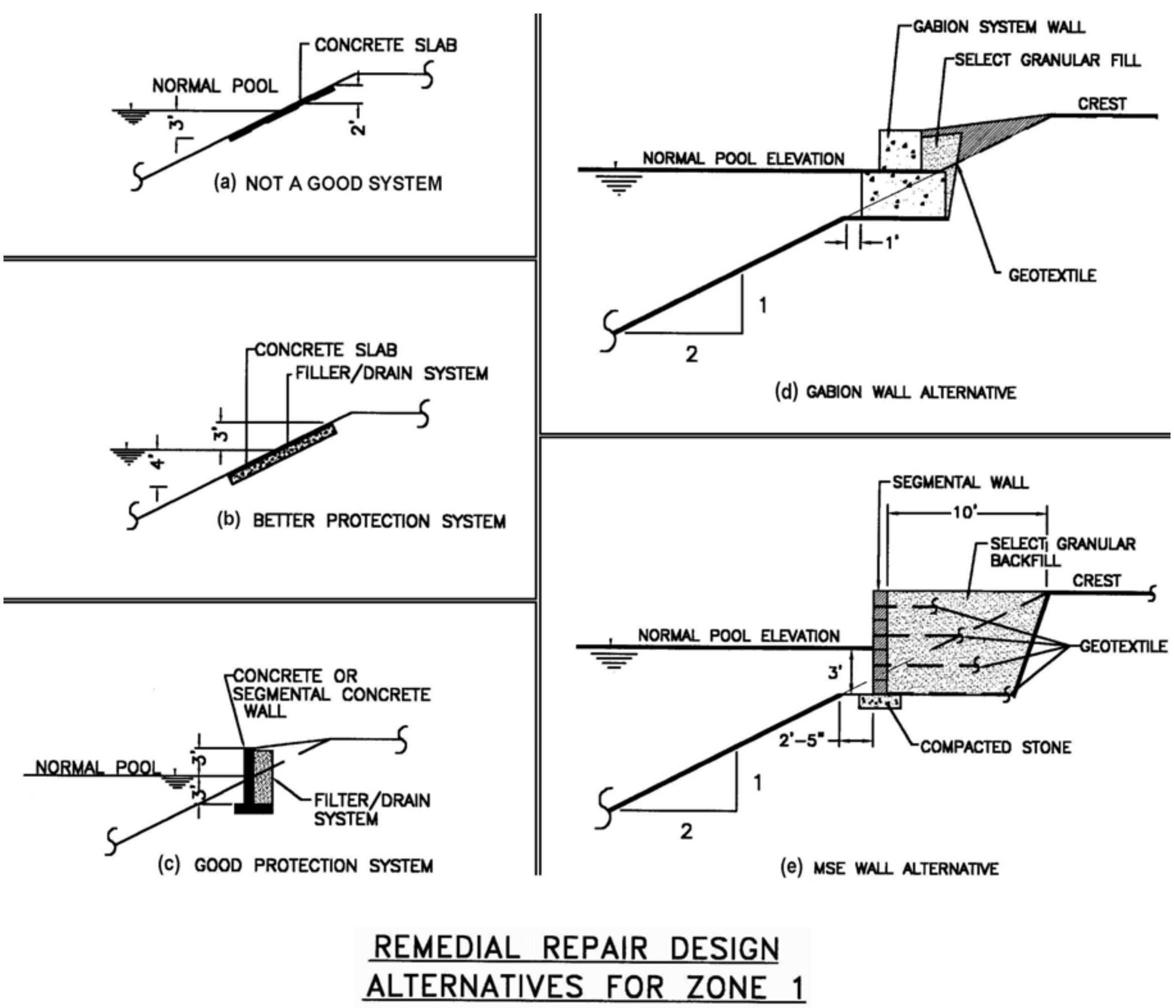

Figure 4

Tree and woody vegetation growth in Zone 1 must be undercut to remove all stumps, rootballs, and root systems developed by tree penetrations as illustrated in Figure 3. The required depth of undercutting typically extends to near the limits of Zone 1, which is about four feet below normal pool elevation. In the case of earthen dams with narrow crest widths, the backslope of the undercut area will typically extend to near the centerline of the dam crest or the downstream limits of Zone 1. Subsequent to undercutting affected areas of Zone 1, the undercut area must be thoroughly inspected to confirm that all major root systems (greater than about one-half inch in diameter) have been removed during the undercutting operation. Following inspection and approval of the undercut area by the engineer, suitable backfill should be placed in the excavation and properly compacted to the dam remediation design limits. Backfill should consist of approved embankment fill material and should be compacted to a minimum of 95 percent of the maximum dry density of the fill soil as determined by the standard Proctor compaction test (ASTM D-698). In conjunction with the undercutting and backfilling, the dam remediation design should include a slope protection system to deter future tree and woody vegetation growth and reduce the potential for wave and surface runoff erosion.

Figures 4(a) through 4(c) illustrate various configurations of rigid (concrete) upstream embankment slope protection systems. Figure 4(a) illustrates a concrete slab being placed directly on the upstream slope from about three feet below to about two feet above normal pool elevation. While this system is somewhat limited relative to the area of protection, the most critical aspect of this system is that it provides no filtration and/or drainage system beneath the concrete slab. Continual wave action and the buildup of hydrostatic pressures beneath the concrete slab will eventually result in downward movement of the slab. Figure 4(b) illustrates a better dam remediation design utilizing a concrete slab slope protection system. This slope protection system has been improved over the original system by covering a larger area of the upstream slope and by providing a filter system beneath the concrete slab protection system. The author is of the opinion that the dam remediation protection system shown in Figure 4(c) is the most desirable and cost effective design for use of reinforced concrete for a protection system. The reinforced concrete wall provides a gentle slope to flat backfill area that can easily be maintained by mowing to preclude tree and woody vegetation growth. In addition, this dam remediation design alternative can be used to provide a wider effective dam crest and provides excellent protection against wave erosion.

NOTE: Reinforced concrete wall and slab systems constructed on the upstream slope must always be provided with filtration/drainage systems to reduce the potential for development of excessive hydrostatic pressures and internal erosion and scour of soil from beneath the structures. The referenced figures are presented for illustrative purposes and should not be used for actual dam remediation design without proper design analyses to confirm any indicated dimensions of the drawings.

Alternative flexible upstream slope protection system designs for use in Zone 1 are shown in Figures 4(d) and 4(e). The author has utilized both of these flexible slope protection systems effectively to reduce potential tree and woody vegetation growth on upstream slopes and to provide resistance to wave and surface erosion. Figure 4(d) illustrates a typical gabion wall system while Figure 4(e) illustrates the use of a Mechanically Stabilized Earth (MSE) wall system for protection of the upstream slope of an earthen dam.

NOTE: Granular backfill material used in design and construction of these flexible wall systems must be protected against soil contamination and internal erosion of retained soil by an effective geotextile filter/drainage material and/or a graded aggregate filter. These figures are presented herein for illustrative purposes and should not be used for actual design without proper design analyses to confirm any indicated dimensions of the drawings.

Inspection and Evaluation Zones 2 and 3

Potential problems associated with tree and woody vegetation growth on earthen dams in identified Zones 2 and 3 are illustrated with dam remediation design procedures in Figure 5. Potential problems illustrated for Zone 2 include the growth of mature trees having stump diameters greater than twelve inches. Mature trees having stump diameters greater than eight inches are illustrated at various locations throughout Zone 3 and in the overlap area of Zones 2 and 3.

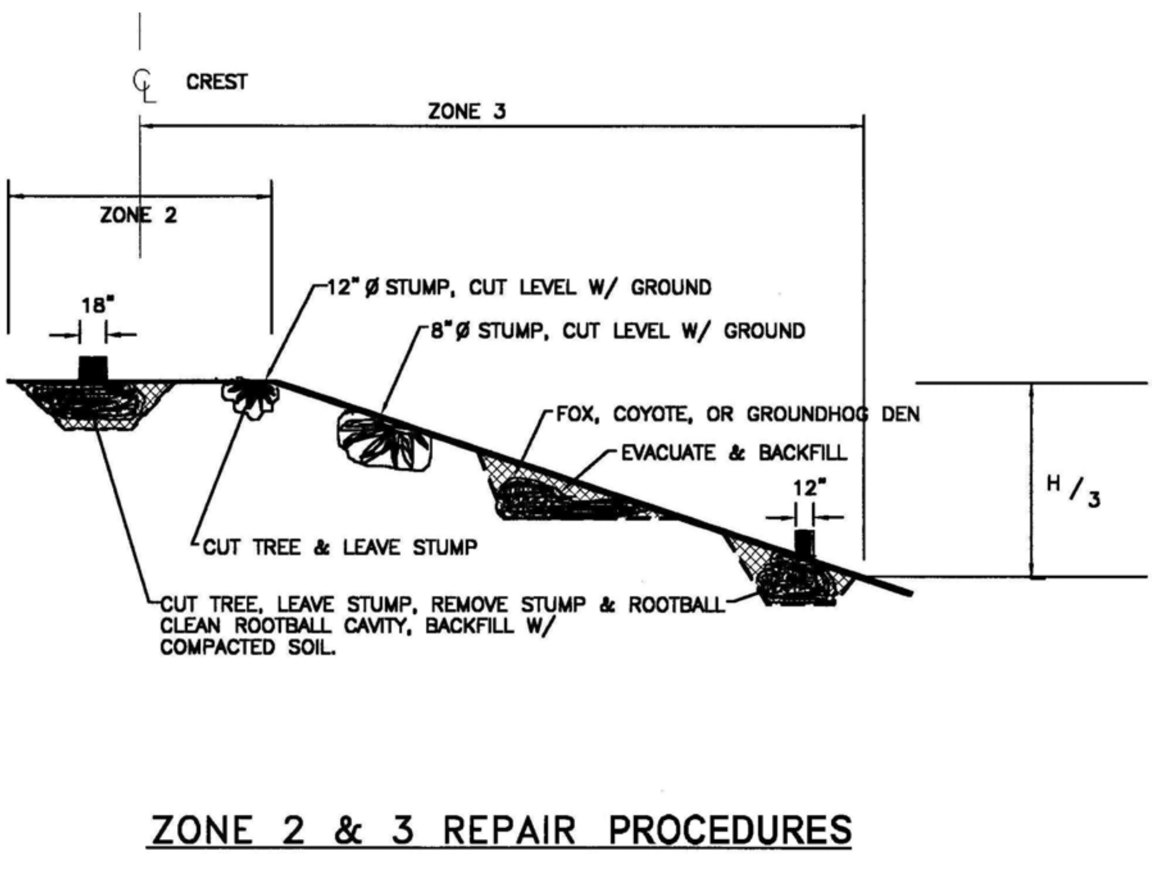

Figure 5

Two dam remediation design procedures are illustrated in Figure 5 for removal of trees of various sizes. This illustration implies that trees located in the overlap area of Zones 2 and 3 having stump diameters less than about twelve inches could be cut flush with the ground and left in place for future treatment of the decayed stump and rootball system. However, removal of all stumps, rootballs and root systems is always the better and more conservative approach to removal of mature trees. Subsequent to cutting of trees having stump diameter less than about twelve inches in the overlap area of Zones 2 and 3, the surface of the stump can be treated with a protective coating similar to polyurethane that will prolong the decaying process. Conversely, the referenced illustration indicates that any trees in Zone 2 upstream of the overlap area of Zones 2 and 3 having stump diameters of twelve inches or greater should be treated by total removal of the tree, stump, rootball, and root system. The suggested dam remediation design and construction procedure suggested for complete removal of trees, stumps, rootballs, and root systems in Zones 2 and 3 consists of the following activities:

1. **Cut** the tree approximately two feet above ground leaving a well-defined stump that can be used in the rootball removal process;

2. **Remove** the stump and rootball by pulling the stump, or by using a track-mounted backhoe to first loosen the rootball by pulling on the stump and then extracting the stump and rootball all together (this is much the same procedure a dentist would use in extracting a tooth);

3. **Remove** the remaining root system and loose soil from the rootball cavity by excavating the sides of the cavity to slopes no steeper than 1:1 (horizontal to vertical) and the bottom of the cavity approximately horizontal; and

4. **Backfill** the excavation with well-compacted soil placed in relatively thin lifts not greater than about eight inches in loose lift thickness. Compaction of backfilled soils in these tree stump and rootball excavations typically requires the use of manually operated compaction equipment or compaction equipment attached to a backhoe.

NOTE: All disturbed areas must be protected by seeding and mulching.

Figure 5 further illustrates that trees located in Zone 3 that have stump diameters greater than about eight inches should be treated by total removal. The removal procedure should be the same as previously described for larger trees in Zone 2. Trees having stump diameter of less than about eight inches could be cut flush with the ground and treated with a waterproofing sealant similar to polyurethane to prolong the stump and rootball decaying process. Again, complete removal of the stumps, rootballs, and root systems of all mature trees is a better and more conservative method of remediation.

Inspection and Evaluation Zone 4

Figure 6 illustrates potential problems associated with tree and woody vegetation growth in Zone 4 of an earthen dam with suggested dam remediation design and construction procedures.

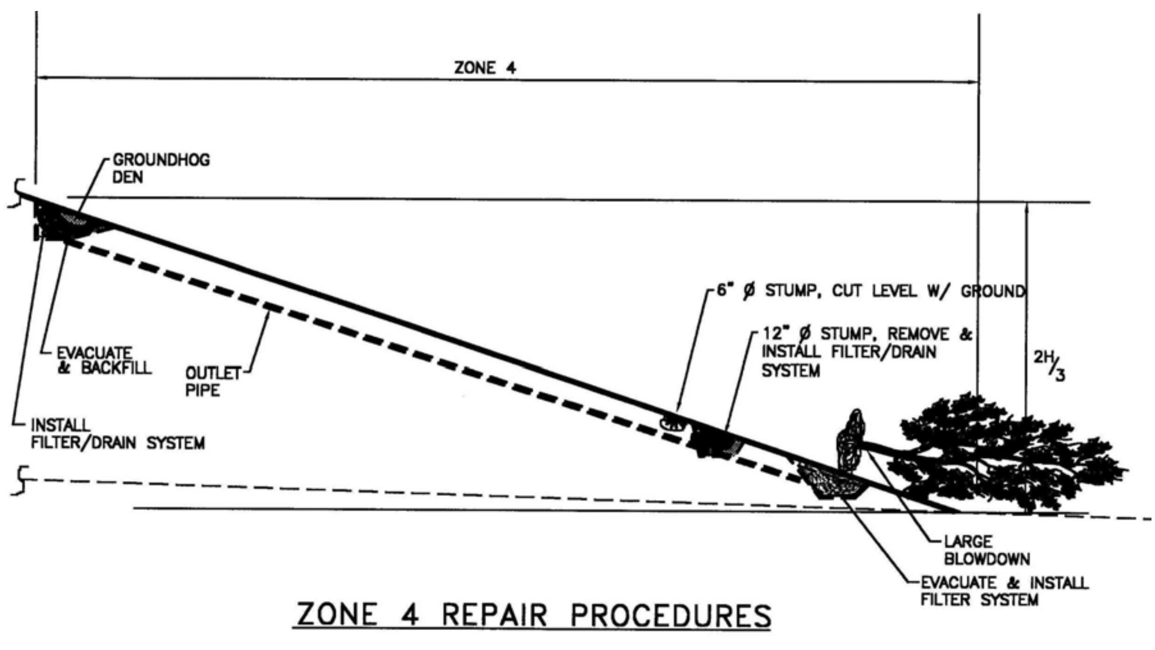

Figure 6

Young immature trees having stump diameters less than about six inches can be removed by cutting flush with the ground and treating the stump with a wood preservative and/or sealant to prolong the decaying process. This procedure is based upon the fact that immature trees of this size typically have not developed a rootball and/or root system that will significantly impact the zone of saturation or the seepage line in Zone 4.

Trees having stump diameters greater than about six inches must be treated by complete removal; however, the dam remediation design and construction procedure for total removal of trees in Zone 4 is somewhat more complicated than total removal of trees in previously discussed zones. Treatment of mature tree penetrations in Zone 4 involves the following activities:

1. **Cut** the tree approximately two feet above ground level leaving a prominent stump for use in the rootball extraction process;

2. **Remove** the stump and rootball by pulling the stump or extracting with a track-mounted backhoe after loosening the rootball by pulling on the stump from different directions;

3. **Clean** the rootball cavity to remove loose soil and the remaining root system by excavating the rootball cavity with maximum 1:1 (horizontal to vertical) side slopes and a horizontal bottom; and

4. **Install** a subdrain and/or filter system in the tree penetration excavation and backfill with compacted soil placed in maximum loose lifts of eight inches.

Note: Backfill placed in all tree removal excavations must be compacted to a minimum of 95 percent of the maximum dry density as determined by ASTM D-698.

Note: Subdrain and/or filter systems installed in tree removal excavations in Zone 4 may be incorporated into major subdrain systems to be installed in the overlap area of Zones 4 and 5.

Inspection and Evaluation Zone 5

The author identified Zone 5 as one of the two most critical zones for tree and woody vegetation growth on an earthen dam. Figure 7 illustrates some of the problems that can occur with tree and woody vegetation growth in Zone 5. The major adverse feature in Zone 5 is typically the interception of the downstream embankment slope by the seepage line. The author is a strong advocate of the installation of embankment subdrain systems during dam remediation design and construction even though the earthen dam may have been provided with an embankment subdrain system during original design and construction.

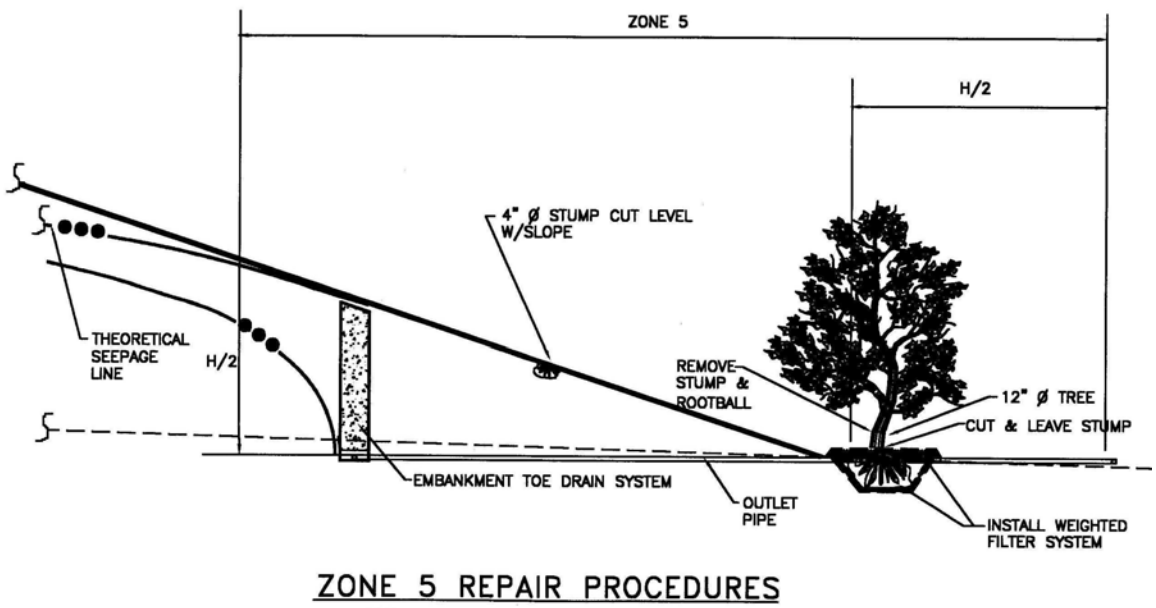

Figure 7

One must understand the impact of tree removal in Zone 5 on the seepage line and the quantity of seepage that will occur subsequent to dam remediation in this zone. As indicated by Figure 7, trees in Zone 5 having stump diameters less than about four inches can be cut flush with the ground and the stump treated with a waterproof sealant to prolong stump and rootball decay. Trees having stump diameters greater than about four inches must be removed completely. If the embankment toe drain or subdrain system is installed in advance of tree removal in Zone 5, the rootball cavity can be backfilled with compacted soil, provided seepage does not emerge from the excavation and/or the tree is located beyond the toe of the embankment slope. Tree rootball cavities existing beyond the toe of the downstream embankment slope generally require the installation of a filter system and in some cases a weighted filter system as indicated in Figure 7. The weighted filter system may be converted to a weighted drain system by installing a drain and outlet pipes connected to the outlet pipe of the embankment subdrain system.

Summary of Dam Remediation Design Considerations

A summary of dam remediation design considerations for treatment of tree and woody vegetation on earthen dams is presented below. Dam remediation design procedures and techniques are presented for treatment of various size trees in the identified dam safety inspection and evaluation zones.

Remedial Repair Zone	Procedures and Techniques
Zone 1	Remove all trees, stumps, rootballs, and root system; clean rootball cavity; and backfill with properly placed and compacted soil backfill. Install tree and woody vegetation and wave erosion protection system on the upstream slope from about four feet below normal pool elevation to about three feet above normal pool elevation.
Zone 2	Cut trees in overlap area of Zone 2 and Zone 3 having stump diameters of twelve inches or less flush with the ground and treat the stump with a waterproof sealant to prolong stump decay.

Completely remove trees having stump diameters of about twelve inches and greater, and backfill rootball cavity with properly compacted backfill soil.

Zone 3

Cut trees having stump diameters of about eight inches and less level with the ground and treat the stump with a waterproof sealant to prolong stump and rootball decay.

Completely remove all trees having stump diameters greater than about eight inches and backfill the cleaned rootball cavity with compacted backfill soil.

Zone 4

Cut all trees having stump diameters of six inches or less flush with the ground and treat the stump with a waterproof sealant to prolong stump and rootball decay.

Remove all trees having stump diameters greater than about six inches, install subdrain and/or filter systems, and backfill with properly compacted soil around the filter/drain system.

Zone 5

Cut all trees having stump diameters of about four inches and smaller flush with the ground and treat the stump to prolong stump and rootball decay.

Install a major embankment toe drain or subdrain system to lower the phreatic surface, filter, collect, and discharge embankment seepage. Incorporate major subdrain with tree rootball and stump removal where possible.

Remove all trees located beyond the toe of the downstream slope having stump diameters greater than about four inches. Install weighted filters and/drain systems in rootball cavities where seepage boiling and soil piping is likely to occur.

Tree and Woody Vegetation Growth Control Program

Many individual dam owners and small dam owner organizations are not financially capable of undertaking comprehensive dam remediation projects in one major construction contract. Therefore, they must undertake dam remediation programs in a sequential manner. The following sequential dam remediation program for controlling tree and woody vegetation growth provides the owner, regulator, and engineer with a reasonable opportunity to effectively evaluate the condition of an earthen dam and to prioritize dam remediation relative to observed dam safety issues.

1. **First Year**: Cut all tall grasses, weeds, underbrush, and trees and woody vegetation having stump diameters of four inches or less flush with the ground and treat all cut stumps with a waterproof preservative to prolong rootball and stump decay.

2. **Second Year**: Cut all trees in Zones 1 through 4 having stump diameters of six inches or less flush with the ground and treat the stumps to prolong stump and rootball decay. Keep all zones mowed and/or maintained to preclude renewed growth of previously cut woody vegetation. Repair most severe animal penetrations that exhibit seepage flows and/or cause unstable slope conditions on Zones 1, 4, and 5.

3. **Third Year**: Initiate comprehensive remedial dam repair investigations, analyses, and preliminary design. Remove all trees from Zones 1 through 3 having stump diameters less than about eight inches by cutting flush with the ground and treating the stump with a preservative to prolong stump and rootball decay.

4. **Fourth Year**: Finalize remedial dam repair design and begin construction of remedial repairs for all plant and animal penetrations that require special remedial dam repair design considerations.

5. **Fifth Year**: Finalize remedial dam repair construction and begin an operation and maintenance program that will preclude the need for future remedial dam repair associated with plant and animal penetrations of earthen dams.

NOTE: **Earthen dams that exhibit severe dam safety deficiencies and dam safety issues that cannot be prolonged as a result of potential imminent dam failure are not subject to the use of this type of sequential dam remediation program!!!**

Chapter 7
Economics of Proper Vegetation Maintenance

Regular maintenance on a dam, especially attention to trees and brush, is known to be critical to dam safety for several reasons (Tschantz, 2000):

- Overturning or uprooting trees causing large voids and reduced freeboard; and/or reduced cross-section for maintaining stability
- Decaying roots of dead trees causing potential seepage paths and piping problems
- Interfering with effective dam safety monitoring, inspection and maintenance for seepage, cracking, sinkholes, slumping, settlement, deflection, and other signs of stress
- Hindering desirable vegetative cover and causing embankment erosion
- Obstructing emergency spillway capacity
- Falling trees causing possible damage to spillways and outlet facilities
- Clogging embankment underdrain systems
- Cracking, uplifting or displacing concrete structures and other facilities
- Inducing local turbulence and scouring around trees in emergency spillways and during overtopping
- Providing cover for burrowing animals
- Loosening compacted soil
- Allowing roots to wedge into open joints and cracks in foundation rock along abutment groins and toe of embankment, thus increasing piping and leakage potential.

State and federal dam safety officials and other dam safety experts agree that trees have no place on dams. Federal agencies and some states do not allow trees to grow on dams. However, it is estimated that about a third of the nation's 77,000 inventoried dams have sufficient woody vegetation to hinder effective dam safety inspections (ASDSO, 2000; Tschantz, 2000). Most states require dam owners to remove trees and undesirable vegetation, but the cost of clearing and grubbing trees and restoring the dam embankment slopes and crest is often cost prohibitive for many dam owners, usually running into thousands of dollars. It would seem that regular control of woody vegetation and maintaining the surface on an earthen is relatively inexpensive, compared to removing trees on and repairing damage from neglected dams such as shown in Figure 1.

Figure 1. Restored Downstream Slope on Fishing Creek Dam, Maryland (1991-92)

Likewise, it is important that owners maintain *desirable* vegetation on their dams on a regular schedule to avoid the expense of periodically removing undesirable heavy brush and mature trees. Early control is generally viewed to be the most cost-effective means of avoiding potential adverse effects on these structures from their continued growth (USBR, 1989). The bulk of maintaining a dam usually involves keeping the grass mowed and brush trimmed. An important question arises, ***"How much is a dam owner justified in spending to maintain a dam on a regular or annual basis to avoid having to bear the heavy cost of removing trees?"*** A correlative question then follows, ***"How often should a dam be mowed to control undesirable woody growth?"***

This chapter attempts to answer these questions, but there are many variables and site-specific factors which need to be considered. Some assumptions also need to be made.

Tree Removal Costs

The cost of clearing and grubbing a dam depends on the size and type of trees, growth density, total job size (i.e., number of acres of trees), location of growth (crest and/or both faces?), embankment face steepness, slope condition (such as degree of wetness or surface texture), degree and type of required surface treatment (backfilling, use of herbicides or bio-barriers, mulching, seeding, fertilizing, etc.), and regional labor and construction differences.

The reader is referred to Table 1 in Chapter 2 and Figure 2 below for unit area tree removal cost comparison experiences reported in a survey by eight state dam safety officials in different regions of the country. The survey data shows that the cost of clearing and grubbing trees and other woody vegetation varies widely within and among states, but generally ranges from about $1000 to $5000 per acre, depending on site-specific conditions (Tschantz, 2000).

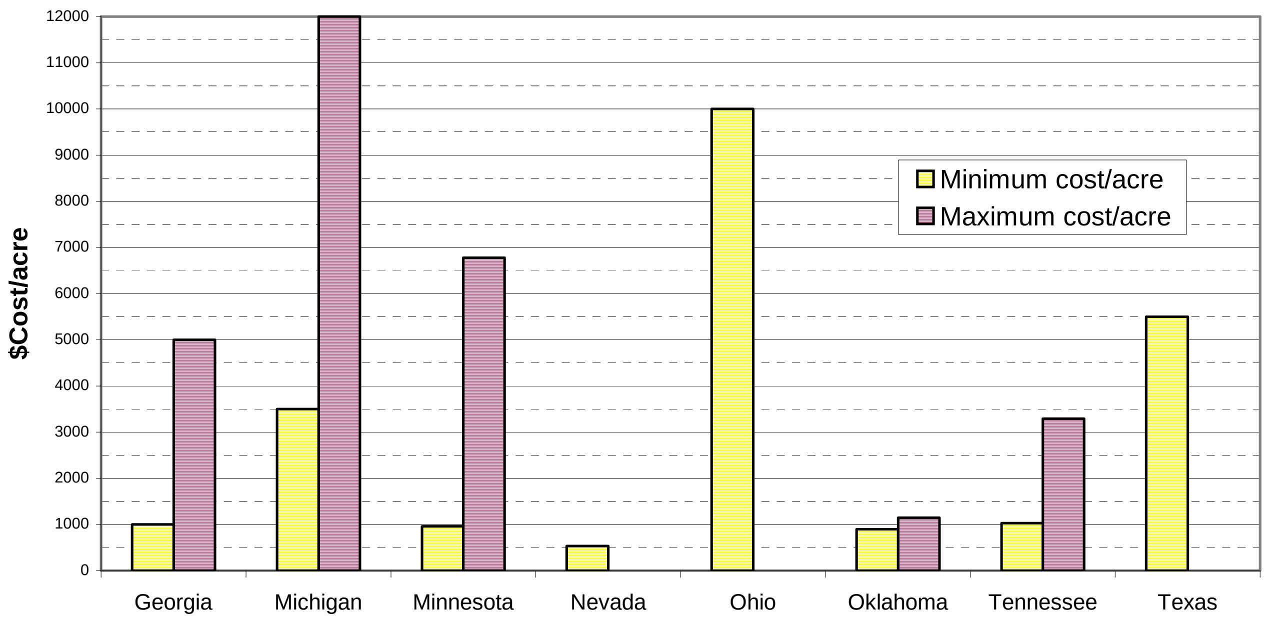

Figure 2. Comparison of tree removal costs per acre of dam surface area reported by 8 states.

These data compare favorably with the $1500 - $3000 bid price data for three Southeastern states discussed earlier in Chapter 2 for cutting trees, removing stumps and rootballs, and grubbing the area to remove roots for different dam conditions. While not included in the above Figure 2 chart data, Massachusetts' dam safety personnel reported in 2000 that, based on its own in-house experience, some local consultants and other sources, "broad area" tree removal costs ranged from $5000 and $6000 per acre or from about $800 to $1000 for individual 18-24 inch trees in their region. One dam safety official, from Tennessee, provided detailed cost data for clearing trees from seven dams in that state from 1995-1999. The cost for clearing and grubbing trees and for reseeding for one typical dam in 1998 is described for the reader in Table 1.

Dam Height	22.3 ft.
Length of Dam	830 ft.
Freeboard above Normal Pool	8 ft.
Density of trees ≤ 6 inches diameter primarily on downstream face	"Moderate"
Approximate surface area of downstream face	≅1.3 acres
Approximate dam face slopes	3H:1V
Amount of brush cutting	"Moderate"
Stumps grubbed out	Yes
Amount of hand work	"Considerable"
Total job cost for clearing, grubbing & reseeding	$4275
Unit area job cost	$3290/acre
Year job completed	1998

Table 1. Tree clearing/grubbing and reseeding cost for a "typical" dam located in Fayette Co., Tennessee (Bentley, 2000)

For comparison purposes, general sitework cost information is available from various construction cost books. General cost data for cutting and clearing out individual trees and for clearing wooded area is shown in Table 2 from one source (BNi, 2001). Indices are normally provided for factoring in regional cost differences. Other cost book sources provide detailed material, labor and equipment requirements for estimating site clearing costs (Means, 2001).

Clear small size wooded area:	
• Light density	$3,607/acre
• Medium density	$4,900/acre
• Heavy density	$5,880/acre
Cut trees & clear out stumps:	
• 9 to 12 inches diameter	$290 per tree
• To 24 inches diameter	$370 per tree
• 24 inches and up	$490 per tree

Table 2. General tree cutting and clearing construction cost data (Bni, 2001).

Similar general tree clearing and grubbing, chipping, seeding, mulching and fertilizing data for estimating construction costs in various regions of the country are also available from other sources (Means, 2001; AC&E, 2002). For example, 2001 Means cost data gives tree cutting, chipping, clearing, and grubbing costs for trees 6-inches or less to be $2975/acre and stump removal to be $1425/acre for a total unit cost of $4400/acre. For trees up to 12 inches the cost is $6925/acre, and for trees up to 24 inches the cost is $15,250/acre (Means, 2001). If burning is allowed, the cut and chip costs can be significantly reduced. Hydro or air seeding, including seed & fertilizer is estimated to be 35¢/square yard (about $1700/acre) (Means, 2001). Mulching would add to this cost.

Maintenance Costs

For most dams, maintenance means keeping the crest and dam embankment slopes mowed and trimmed. The cost of mowing a dam depends on many factors, including geographical location, accessibility, condition of slopes as discussed above, degree of public use and desired aesthetics, type of vegetation and frequency of mowing. Cost also depends on whether the work is done directly by private owners, subcontracted commercially, or done by in-house state or federal maintenance crews. Table 3 summarizes these factors. The availability of slope mowers as illustrated in

Table 3. Factors Affecting Dam Maintenance Cost

• Region of country	• Embankment slope steepness
• Type of ground cover & vegetation	• Mowing frequency
• Accessibility to dam	• Local labor costs
• Surface condition	• Type of maintenance provider
• Size of job (surface area)	• Degree of public use; aesthetics

Figure 3 illustrates the use of a slope mower for easing the burden of maintenance for state and federal agencies and for other multiple or large dam owners.

Figure 3. Example of slope mower (Terratrac© photo used with permission from AEBI North America, Inc.)

Most public works dams usually get mowed at least twice a year, in the early fall and late spring. Many subdivisions, homeowner associations, and/or residential developments typically mow dams, located in high-visibility areas, about once a month to every six weeks. One geotechnical consultant, who specializes in embankment dam rehabilitation, uses a “rule of thumb” mowing estimate of about $100 per acre with a minimum fee of $200 to $250 per mowing job (Marks, 2000). 1998 bid prices for mowing general right-of-way areas along East Tennessee highways averaged about $32 per acre, with a range of about $28 to $38 per acre for four jobs (TDOT-Region 1, 2000).

The U. S. Corps of Engineers, Nashville District, furnished recent annual mowing costs for three District dams, including some proximate recreation zones, having total mowing areas ranging from 8 to 27 acres. The average mowing cost for these three dams was about $55/acre and ranged from $43.42 to $78.24/acre (Corps, 2000).

The Tennessee Valley Authority furnished similar estimated in-house annual mowing cost data associated with general dam safety grounds maintenance activities for its dams. However, TVA’s annual cost data included labor, supervision, slope mower fuel, parts, equipment, etc. and averaged slightly over $600/acre for 31 saddle and main embankment dams with a cost range from about $45 to $2000/acre (TVA, 2000).

A dam owner is advised that, in addition to mowing cost, the total annual maintenance expenditure should also include the expenses of dam inspection(s), minor repairs and rehabilitation of various structural components, removal of obstructions from emergency and service spillways, and other safety or operational costs associated with maintaining a dam.

Example maintenance cost analysis

The following example illustrates a rational procedure for answering the two earlier questions: 1) how much should a dam owner spend yearly to maintain a typical earthen dam to control trees and woody vegetation growth while avoiding bearing the cost of removing mature trees at a later date?

and 2) how often should an earthen dam be mowed to maintain acceptable ground covering vegetation? Maintenance expense in this example is for mowing only. Assumptions for this example are as follows:

1. **Dam Description:**
    - Length = 900 feet
    - Crest width = 15 feet
    - Embankment slopes (upstream and downstream) = 3:1 (horizontal to vertical)
    - Height = 35 feet
    - Normal pool = 10 feet below crest
    - Nearly vertical end abutments
2. **Economic Analysis Assumptions:**
    - 30-year project analysis period
    - Annual rates of return rates = 4, 6, 8, 10, and 15%
    - Zero annual inflation on recurring costs
3. **Maintenance Assumptions:**
    - Assume that 10-year old brush and trees are mature enough to significantly hinder effective inspection. Trees of this age can reach in size from 6 to 8 inches in diameter, depending upon species, tree density and other environmental conditions
    - Mowing costs = $100 per acre (with a minimum fee of $250 per mowing)
    - Trees can grow on all exposed upstream and downstream embankment slopes and the crest of the dam
    - Assume tree removal, including clearing and grubbing, costs = $2500/acre
    - Seeding & mulch not included in surface restoration costs.

Economic Analysis Calculations

Charts have been prepared and attached at the end of this chapter as a tool in helping to estimate mowing areas (or tree stand estimates) for different dam configurations. Chart 1 can be used to determine dam embankment slope area in acres for four slopes ranging from 1.5:1 to 3:1 (horizontal to vertical) and for dam lengths of 200 and 500 feet. Linear interpolations and ratio extrapolations can be made for other slope configurations and dam embankment lengths, respectively. Note that when determining the area of an upstream embankment slope, the equivalent dam height entered into the chart is the vertical distance between normal pool and crest elevation. Chart 2 is used to estimate dam crest area for three convenient lengths; crest areas for other actual dam crest lengths can be calculated from direct ratios. A self-guiding Chart 3 is provided to allow for small abutment area reduction corrections to be estimated and applied to slope area determined from Chart 1.

For the assumed example dam given above, make the following computations:

1. Use the attached charts to estimate total mowable and potential tree-covered dam area:

   (a) Downstream Embankment Slope (35 ft. high, 3:1 slope, 900 ft. length):
   A_1 = 1.28 acres x 900/500 = 2.3 acres (Use Chart 1; no abutment area reduction correction∗)

   (b) Crest (15 ft. wide, 900 ft. length)
   A_2 = 0.17 x 900/500 = 0.31 acres (Use Chart 2)

   (c) Upstream Embankment Slope (10 ft. high exposure, 3:1 slope, 900 ft. length):
   A_3 = 0.37 x 900/500 = 0.67 acres (Use Chart 1)

   (d) Estimated total dam area to be restored ≈ 2.3 + 0.3 + 0.7 = 3.3 acres

2. Estimated 10-year cycle clearing and grubbing job costs, over a 30-year analysis period, starting with end of 10th year:

   Total Estimated Cost = 3.3 acres x $2500 per acre = $8250

∗ For this example, the abutment slopes are assumed vertical or 0^{o}, but total slope area reduction for a 30^{o} abutment would be only ≈ 0.25 acres (see Chart 3).

3. Find the annual break-even cost balance between mowing and recurring clearing and grubbing, using the sinking fund factor (SFF), assuming 4, 6, 8, 10, and 15% discount rates for a 30-year period. A sinking fund is an equivalent annual amount to be set aside and left to grow at a certain interest rate into a specified amount at the end of a predetermined time period.

It is assumed in this example that mowing and clearing and grubbing costs do not change over the 30-year analysis period and that the dam safety inspections are not hindered for up to 10-year tree growth. By assuming a zero inflation rate for these costs, the results of this exercise are not dependent on the selected period of analysis; therefore, the annual values are valid for a 50- or 100-year period as well as for a 30-year period.

- ♦ Annualized clearing and grubbing cost = \$8250 x (SFF, i, N years)

  where the SFF = $i/[(1 + i)^N – 1]$

  and i = discount rate (expressed as fraction)
  N = time period, in years, between tree clearing and grubbing

- ♦ Mowing job cost = 3.3 acres x \$100/acre = \$330

- ♦ Equivalent number of mowings per year = (Annualized clearing & grubbing costs)/(\$330 per mowing)

The following Table 4 shows that the annualized clearing and grubbing costs and equivalent number of annual mowings varies somewhat with the discount rate. For this example, at a 6% discount rate, this dam owner would be able to justify about two mowings per year at \$330 per mowing to avoid having to shell out \$8250 every 10 years for clearing the dam of trees and woody vegetation. The owner could afford to mow once or twice a year, even at a relatively high 10%

Assumed discount rate, i	Annualized 10-yr frequency clearing and grubbing cost	Equivalent number of mowings per year
4%	$687	2.1
6%	$626	1.9
8%	$569	1.7
10%	$518	1.6
15%	$406	1.3

Table 4. Annualized Cost Comparison for Assumed $2500 per acre for a 10-Year Cycle Clearing and Grubbing Payout.

discount rate. By mowing on a regular basis, the owner would also realize side benefits of a more aesthetically pleasing dam -- one that would be viewed more as a community asset than a liability, be accessible and inspection friendly, and be less attractive to unwanted burrowing animals.

If $5000 per acre or $16,500 for 3.3 acres, rather than the $2500 per acre and $8,250 per job, had been assumed for tree clearing costs over the 10-year cycle control period, the justifiable annual costs for mowing would double for the same discount rates. For this higher restoration cost, the owner would be justified to mow 3 or 4 times per year, depending on the cost of money. The following Table 5 illustrates this assumption.

Assumed discount rate, i	Annualized 10-yr frequency clearing and grubbing cost	Equivalent number of mowings per year
4%	$1374	4.2
6%	$1252	3.8
8%	$1138	3.4
10%	$1036	3.1
15	$ 813	2.5

Table 5. Annualized Cost Comparison for Assumed $5000 per acre for a 10-Year Cycle Clearing and Grubbing Payout.

For a more conservative 5-year tree growth cycle and a $2500 clearing and grubbing cost assumption, the annualized clearing and grubbing costs would be $1523, $1464, $1406, $1351, and $1224 for the same discount rates, respectively. The corresponding justifiable mowings would be 4.6, 4.4, 4.3, 4.1, and 3.7 per year. Similarly, justifiable mowings for an assumed $5000 clearing and grubbing cost would double the justifiable mowings to 9.2, 8.9, 8.6, 8.2, and 7.4 per year. Figure 4 compares 5 and 10-year annualized costs for $2500/acre clearing and grubbing payouts.

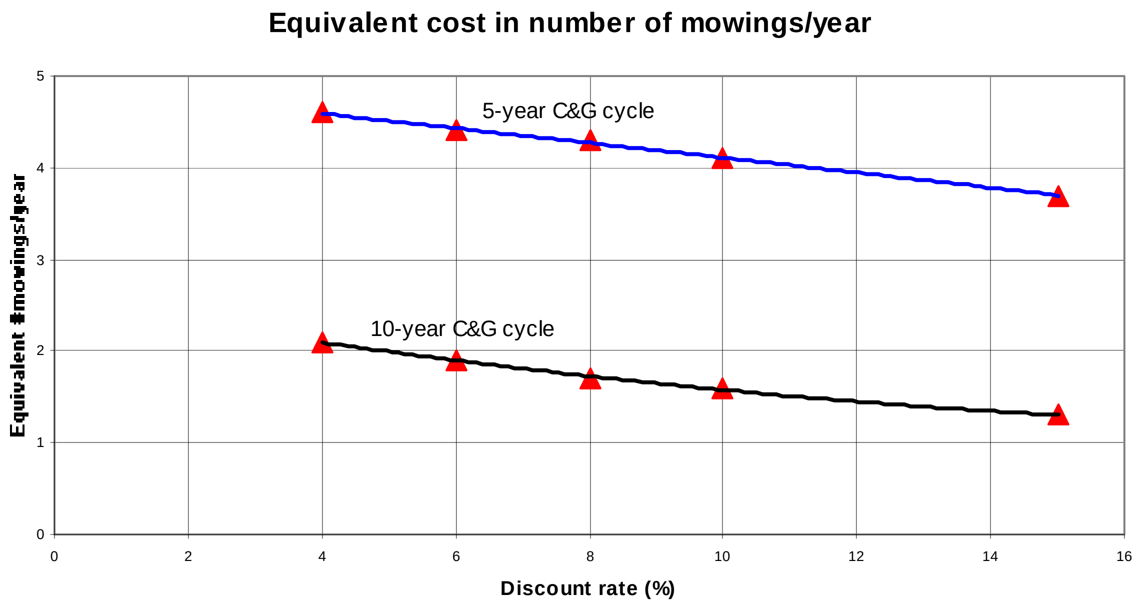

Figure 4. Comparison of Annual Tree Clearing and Grubbing Costs for 5 and 10-Year $2500/acre payouts.

Realistically, unit area costs would likely be reduced substantially for more frequent clearing and grubbing or bush hogging of smaller growth. Obviously, the above values will be different if the costs are assumed to escalate each year. For example, assuming a modest 3% annual inflation factor results in an increase in the clearing and grubbing cost from $8250 to $14,900 for a 30-year analysis period.

Summary

Cost data obtained from the private, state and federal sectors show that dam maintenance and tree removal and dam restoration costs can vary widely, depending on several factors.

It has been demonstrated, by way of example and reasonable cost assumptions, that dam owners can economically justify mowing their embankments 2 to 8 times a year, depending on local factors and costs, to prevent trees and other woody vegetation from maturing to a point that could compromise dam safety and require major capital outlays. It appears extremely economically efficient for dam owners to control woody growth on at least an annual basis, to avoid the large cost of removing mature brush and trees every 5 to 10 years and to comply with state inspection requirements.

So, how much should a dam owner spend on maintaining his dam? At least enough to keep it mowed and trimmed a couple times a year – probably something in the neighborhood of $500 to a $1000 annually for most dams, if contracted. Keeping a dam mowed a minimum of twice a year does not appear to be an unreasonable financial burden for most small dam owners. A dam owner must understand that spending a few dollars on annual vegetative maintenance and upkeep, such as mowing, will pay dividends over the long run for an asset (and potential liability) such as a dam.

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Chart 1. Dam face area for different geometries

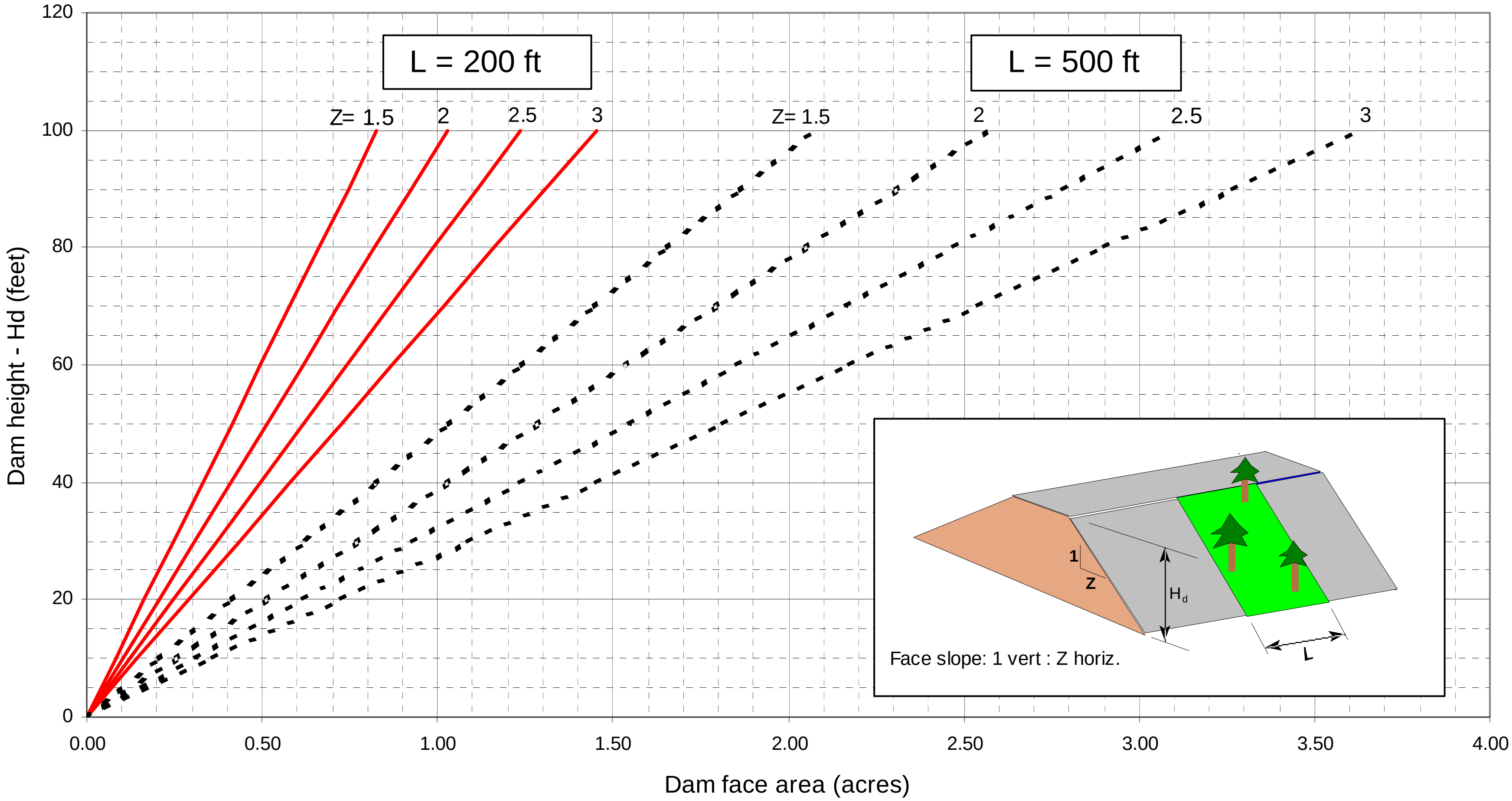


Chart 2. Dam crest area by width and length

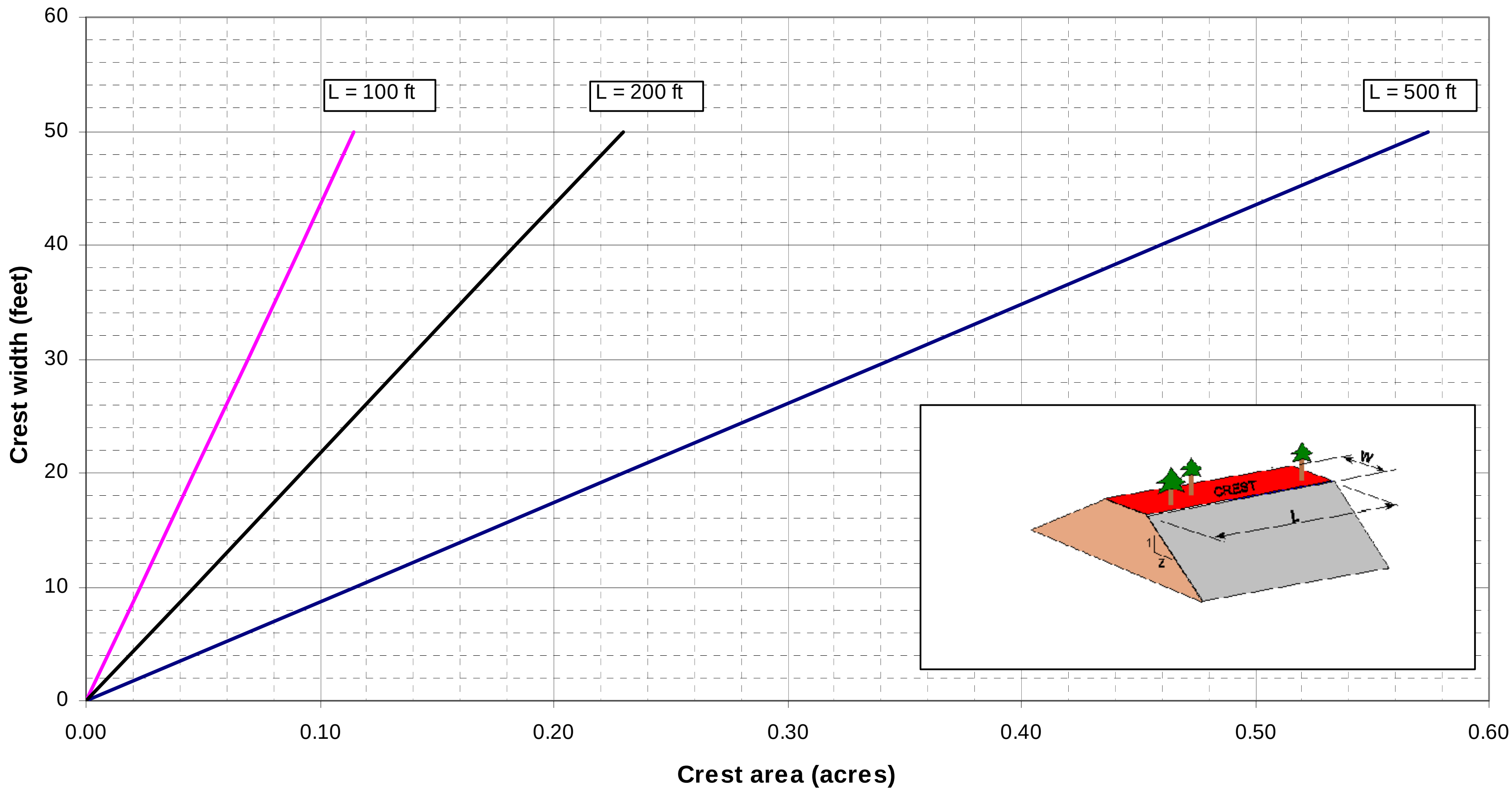
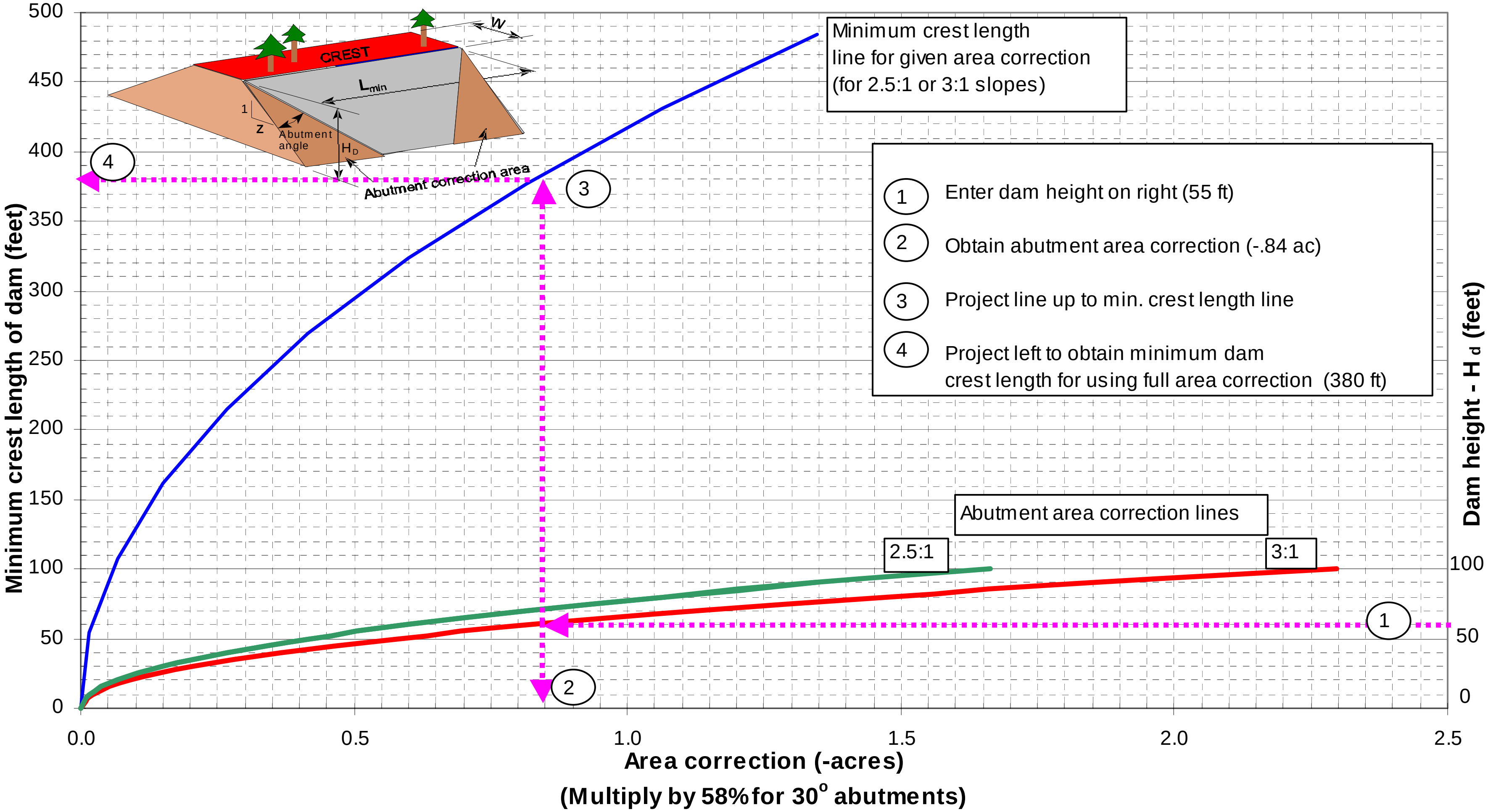


Chart 3. Abutment area corrections vs. dam height for 2.5H:1V & 3H:1V side slopes, with 45° abutment angle and corresponding minimum dam crest length



Guide to Concrete Repair

United States Department of the Interior
Bureau of Reclamation
Technical Service Center

Preface

This guide contains the expertise of numerous individuals who have directly assisted the author on many concrete repair projects or freely shared their concrete repair knowledge whenever requested. Their substantial contributions to the preparation of this guide are acknowledged and appreciated. Some of the material in this guide originated in the various editions of Reclamation's *Concrete Manual*. The author edited, revised, or updated this information for inclusion herein.

Individuals who have been especially helpful to the author include James E. Backstrom, former Reclamation engineer, mentor, and friend, deceased; Edward M. Harboe, Reclamation engineer, retired; U. Marlin Cash, Reclamation technician, deceased; Dennis O. Arney, Reclamation technician, retired; G.W. DePuy, Reclamation engineer, former supervisor and friend, retired; and Kurt D. Mitchell, Reclamation technician. Dr. Dave Harris, Manager, Materials Engineering and Research Laboratory, obtained much of the funding to prepare this guide; Kurt F. Von Fay, Civil Engineer, Materials Engineering and Research Laboratories, performed the peer review; James E. McDonald, Structures Laboratory, Waterways Experiment Station, U.S. Army Corps of Engineers, provided editorial reviews of selected information and many useful sug-gestions and participated with the author in several cooperative Reclamation—U.S. Corps of Engineers concrete repair programs. The assistance of these and numerous other engineers and technicians is gratefully acknowledged.

Contents

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Chapter I

Repair of Concrete

1. Introduction.—For many years, the Bureau of Reclamation (Reclamation) has published the *Concrete Manual*, the first edition dated July 1938, and more recently, the *Standard Specifications For Repair of Concrete, M-47*, the first edition dated November 1970. The subsequent revisions of these two documents (Bureau of Reclamation, 1975 and 1996), particularly chapter 7 of the *Concrete Manual*, have formed the basis for nearly all concrete repair performed on Reclamation projects during the past 25 years.

Reclamation operates and maintains a water resources infrastructure, located primarily in the harsh climatic zones of the Western United States, valued at over $17 billion. It has become apparent that there is need for modernization and expansion of the information on the methods, materials, and procedures of concrete repair originally found in chapter 7 of the *Concrete Manual*. This *Guide to Concrete Repair* results from recognition of that need. It is designed to serve as a companion document to the "Standard Specifications for Repair of Concrete" included in appendix A of this guide.

This guide first discusses Reclamation's methodology for concrete repair. It then addresses the more common causes of damage to Reclamation concrete, including suggestions of the types of repair methods and materials most likely to be successful in repairing concrete damage resulting from those causes. Finally, the guide contains a detailed description of the uses, limitations, materials, and procedures of each of the standard repair methods/materials included in the "Standard Specifications for Repair of Concrete."

2. Maintenance of Concrete.—Modern concrete is a very durable construction material and, if properly proportioned and placed, will give very long service under normal conditions. Many Reclamation concrete structures, however, were constructed using early concrete technology, and they have already provided well over 50 years of service under harsh conditions. Such concrete must be inspected regularly to ensure that it is receiving the maintenance necessary to retain serviceability. Managers and foremen of operation and maintenance crews must understand that, with respect to concrete, there is no such thing as economical deferred maintenance. Failure to promptly provide the proper necessary maintenance will simply result in very expensive repairs or replacement of otherwise useful structures. Figures 1 and 2 demonstrate the folly of inadequate or inappropriate maintenance. These two structures now require replacement at a cost tens of times greater than that of the preventive maintenance that could have extended their serviceability indefinitely.

Experience has shown that there are certain portions of exposed concrete structures more vulnerable than others to deterioration from weathering in freezing climates. These are exposed surfaces of the top 2 feet of walls, piers, posts, handrails, and parapets; all of curbs, sills, ledges, copings, cornices, and corners; and surfaces in contact with spray or water at frequently changing levels during freezing weather. The durability of these surfaces can be considerably improved and serviceability greatly prolonged by preventive maintenance such as weatherproofing treatment with concrete sealing compounds (sections 35 and 38).

Figure 1.—Lack of maintenance has resulted in near loss of this irrigation structure.

Figure 2.—Deferred maintenance has allowed freezing and thawing deterioration to seriously damage this structure.

Selecting the most satisfactory protective treatment depends to a considerable extent upon correctly assessing the exposure environment. Concrete sealing compounds and coatings that provide good protection from weathering in an essentially dry environment may perform poorly in the presence of an abundance of water such as on some bridge curbs and railings, stilling basin walls, and piers. Freezing and thawing tests of concrete specimens protected by a variety of concrete sealing compounds and coatings, including linseed oil, fluosilicates, epoxy and latex paints, chlorinated rubber, and water-proofing and penetrating sealers, have been performed in Reclamation laboratories. These tests indicate that proprietary epoxy formulations, siloxane and silane formulations, and the high molecular weight methacrylate formulations (section 35) clearly excel in resisting deterioration caused by repeated freezing and thawing in the presence of water. None of these formulations, however, will totally "waterproof" concrete. That is, they will not prevent treated concrete from absorbing water and becoming saturated under conditions of complete and long-term submergence.

The performance of new concrete sealing compounds is continually being evaluated by the Materials Engineering and Research Laboratory, Code D-8180, located in Denver, Colorado. If use of these materials is being considered, the project should contact the Denver Office for the latest recommendations on materials, methods of mixing, application, curing, and precautions to be exercised during placement.

Except for hand-placed mortar restorations of deteriorated concrete (section 25), concrete sealing compounds are ordinarily not applied on new concrete construction. The treatments are most commonly used on older surfaces when the earliest visible evidence of weather-ing appears. That is, the treatment is best used before deterioration advances to a stage where it cannot be arrested. Such early evidence consists primarily of fine surface cracking, close and parallel to edges and corners. The need for protection also may be indicated by pattern cracking, surface scaling or spalling, and shrinkage cracking. By treatment of these vulnerable surfaces in the early stages of deterioration, later repairs may be avoided or at least postponed for a long time.

Linseed oil-turpentine-paint preparations have been widely used in the past by Reclamation to retard concrete deterioration caused by weathering. These preparations, when applied correctly, have been effective. The terminology "linseed oil treatment," however, has caused many users to believe that a simple coating of boiled linseed oil would protect concrete from weathering. Such is not the case. The treatment recommended by Reclamation consisted of a number of steps including acid washing surface preparation, 48-hour drying, and application of two or more coats of a hot linseed oil-turpentine mixture followed by two or more coats of white lead paint, the first of which was thinned with linseed oil and turpentine. The modern concrete sealing compounds are much simpler to apply and provide superior protection to the concrete. The use of the linseed oil-turpentine-oil paint system is no longer recommended.

3. General Requirements for Quality Repair.—The term "concrete repair" refers to any replacing, restoring, or renewing of concrete or concrete surfaces after initial placement. The need for repairs can vary from such minor imperfections as she-bolt holes, snap-tie holes, or normal weathering to major damages resulting from water energy or structural failure. Although the procedures described may initially appear to be unnecessarily detailed, experience has repeatedly demonstrated that no step in a repair operation can be omitted or carelessly performed without detriment to the serviceability of the work. Inadequate workmanship, procedures, or materials will result in inferior repairs which will ultimately fail at significant cost.

(a) Workmanship.—It is the obligation of the construction contractor or operation and maintenance crew to repair imperfections or damage in concrete so that repairs will be serviceable and of a quality and durability comparable to the adjacent portions of the structure. Repair personnel are responsible for making repairs that are inconspicuous, durable, and well bonded to existing surfaces. Since most repair procedures involve predominantly manual operations, it is particularly important that both foremen and workmen be fully instructed concerning procedural details of repairing concrete and the reasons for the procedures. Workmen should also be apprized of the more critical aspects of repairing concrete. Constant vigilance must be exercised by the contractor's and/or the Government's forces to ensure maintenance of the necessary standards of workmanship. Employment of dependable and capable workmen is essential. Well trained, competent workmen are particularly essential when epoxy, polyurethane, or other resinous materials are used in repair of concrete.

(b) Procedures.—Serviceable concrete repairs can result only if correct methods are chosen and techniques are carefully performed. Wrong or ineffective repair or construction procedures, coupled with poor workmanship, lead to inferior repairs. Many proven procedures for making high quality repairs are detailed in this guide; however, not all procedures used in repair or maintenance are discussed. Therefore, it is incumbent upon the craftsmen doing the work to use procedures that have been successful or that have a proven high reliability factor.

Repairs made on new or old concrete should be made as soon as possible after such need is realized and evaluated. On new work, the repairs that will develop the best bond and, thus, are the most likely to be as durable and permanent as the original work are those that are made immediately after stripping of the forms while the concrete is quite green. For this reason, repairs to newly constructed concrete should be completed within 24 hours after the forms have been removed.

Before repairs are commenced, the method and materials proposed for use should be approved by an authorized inspector. Routine curing should be interrupted only in the area of repair operations.

Effective repair of deteriorated portions of concrete structures cannot be ensured unless there is complete removal of all deteriorated or possibly affected concrete, careful replacement in strict accordance with a standard or approved procedure, and assurance of secure anchorage and effective drainage when needed. Consequently, work of this type should not be undertaken unless or until ample time, personnel, and facilities are available. Only as much of this work should be undertaken as can be completed correctly; otherwise, the work should be postponed, but not so long as to allow further deterioration. Repairs should be made at the earliest possible date.

(c) Materials.—Materials to be used in concrete repair must be high quality, relatively fresh, and capable of meeting specifications requirements for the particular application or intended use. Mill reports or testing laboratory reports should be required of the supplier or manufacturer as an indication of quality and suitability. Short of this requirement, certifications stating that the materials meet certain specifications should be required of the supplier. Due to the high cost associated with the subsequent removal and replacement of new, unknown, or unproven materials if they prove unsuitable for the job, such materials should never be used in concrete repair unless (1) the standard repair materials have been determined unsuitable and (2) the owners and all other parties to the repair have been informed of the need to use nonstandard materials and the associated risk.

Materials selected for repair application must be used in accordance with manufacturers' recommendations or other approved methods. Mixing, proportioning, and handling must be in accordance with the highest standards of workmanship.

Chapter II

A Concrete Repair System

Concrete repairs have occurred on Reclamation projects since the first construction concrete was placed in 1903. Unfortunately, even though the best available materials were used, many repair failures have occurred during the 90 years since that first concrete construction. In evaluating the causes of these failures, it was learned that it is essential to consistently use a systematic approach to concrete repair. There are several such repair approaches or systems currently in use. The U.S. Army Corps of Engineers lists an excellent system in the first chapter of its manual, *Evaluation and Repair of Concrete Structures* (U.S. Army Corps of Engineers, 1995). Other organizations, such as the American Concrete Institute, the Portland Cement Association, the International Concrete Repair Institute, and private authors (Emmons, 1994) have also published excellent methodologies for concrete repair. This guide will not attempt to discuss or evaluate these systems for any particular set of field conditions. Rather, the following seven-step repair system, which has been developed, used, and evaluated by Reclamation over an extended period of time, is presented. This methodology has been found suitable for repairing construction defects in newly constructed concrete as well as old concrete that has been damaged by long exposure and service under field conditions.

This system will be found most useful if followed in a numerically sequential, or step wise manner. Quite often, the first questions asked when the existence of deteriorated or damaged concrete becomes apparent are: "What should be used to repair this?" and "How much is this going to cost?". These are not improper questions. However, they are questions asked at an improper time. Ultimately, these questions must be answered, but pursuing answers to these questions too early in the repair process will lead to incorrect and, therefore, extremely costly solutions. If a systematic approach to repair is used, such questions will be asked when sufficient information has been developed to provide correct and economical answers.

Reclamation's Concrete Repair System

1. Determine the cause(s) of damage
2. Evaluate the extent of damage
3. Evaluate the need to repair
4. Select the repair method
5. Prepare the old concrete for repair
6. Apply the repair method
7. Cure the repair properly

4. Determine the Cause(s) of Damage.— The first and often most important step of repairing damaged or deteriorated concrete is to correctly determine the cause of the damage. If the cause of the original damage to concrete is not determined and eliminated, or if an incorrect determination is made, whatever damaged the original concrete will likely also damage the repaired concrete. Money and effort spent for such repairs is, thus, totally wasted. Additionally, larger and even more costly replacement repairs will then be required.

If the original damage is the result of a one- time event, such as a river barge hitting a bridge pier, an earthquake, or structural overload, remediation of the cause of damage need not be addressed. It is unlikely that such an event will occur again. If, however, the cause of damage is of a continuing or recurring nature, remediation must be addressed, or the repair method and materials must in some manner be made resistant to predictable future damage. The more common causes of damage to Reclamation concrete are discussed in chapter III. A quick review of these common causes of damage reveals that the majority of them are of a continuing or recurring nature.

It is important to differentiate between causes of damage and symptoms of damage. In the above case of the river barge hitting the bridge pier, the cause of damage is the impact to the concrete. The resultant cracking is a symptom of that impact. In the event of freezing and thawing deterioration to modern concrete, the cause of the damage may well lie with the use of low quality or dirty fine or coarse aggregate in the concrete mix. The resultant scaling and cracking is a symptom of low durability concrete. The application of high cost repairs to low quality concrete is usually economically questionable.

It is somewhat common to find that multiple causes of damage exist (section 23). Improper design, low quality materials, or poor construction practices reduce the durability of concrete and increase its susceptibility to deterioration from other causes. Similarly, sulfate and alkali-silica deterioration cause cracks in the exterior surfaces of concrete that allow accelerated deterioration from cycles of freezing and thawing. The deterioration resulting from the lowered resistance to cyclic freezing and thawing might mask the original cause of the damage.

Finally, it is important to fully understand the original design intent and concepts of a damaged structure before attempting repair. Low quality local aggregate may have intentionally been used in the concrete mix because the costs associated with hauling higher quality aggregate great distances may have made it more economical to repair the structure when required at some future date. A classic example of misunderstanding the intent of design recently occurred on a project in Nebraska. A concrete sluiceway that would experience great quantities of waterborne sand was designed with an abrasion-resistant protective overlay of silica fume concrete. This overlay was intentionally designed so that it would not bond to the base concrete, making replacement easier when required by the anticipated abrasion-erosion damage. This design concept, however, was not communicated to construction personnel who became deeply concerned when the silica fume overlay was found to be "disbonded" shortly after placement and curing was completed. Some difficulty was experienced in preventing field personnel from requiring the construction contractor to repair a perfectly serviceable overlay that was performing exactly as intended.

5. Evaluate the Extent of Damage.—The next step of the repair process is to evaluate the extent and severity of damage. The intent of this step is to determine how much concrete has been damaged and how this damage will affect serviceability of the structure (how long, how wide, how deep, and how much of the structure is involved). This activity includes prediction of how quickly the damage is occurring and what progression of the damage is likely.

The importance of determining the severity of the damage should be understood. Damage resulting from cyclic freezing and thawing, sulfate exposure, and alkali-aggregate reaction appears quite similar. The damage caused by alkali-aggregate reaction and sulfates is far more severe than that caused by freeze-thaw, although all three of these causes can result in destruction of the concrete and loss of the affected structure. The main difference in severity lies in the fact that proper maintenance can reduce or eliminate damage caused by freeze-thaw. There is no proven method of reducing damage caused by alkali-aggregate reaction or sulfate exposure.

The most common technique used to determine the extent of damage is sounding the damaged and surrounding undamaged concrete with a hammer. If performed by experienced personnel, this simple technique, when combined with a close visual inspection, will provide the needed information in many instances of concrete damage. In sounding suspected delaminated or disbonded concrete, it should be remembered that deep delaminations or delaminations that contain only minute separation may not always sound drummy or hollow. The presence of such delaminations can be detected by placing a hand close to the location of hammer blows or by closely observing sand particles on the surface close to the hammer blows. If the hand feels vibration in the concrete, or if the sand particles are seen to bounce however slightly due to the hammer blows, the concrete is delaminated.

An indication of the strength of concrete can also be determined by hammer blows. High strength concrete develops a distinct ring from a hammer blow and the hammer rebounds smartly. Low strength concrete resounds with a dull thud and little rebound of the hammer. More detailed information can be obtained by using commercially available rebound hammers, such as the Schmidt Rebound Hammer.

Cores taken from the damaged areas can be used to detect subsurface deterioration, to determine strength properties through laboratory testing, and to determine petrography. Petrographic examination of concrete obtained by coring can also be very useful in determining some causes of deterioration.

There are a number of nondestructive testing methods that can be used to evaluate the extent of damage (Poston et al., 1995). The above-mentioned Schmidt Rebound Hammer is perhaps the cheapest and simplest to use. Ultrasonic pulse velocity and acoustic pulse echo devices measure the time required for an electronically generated sound wave to either travel through a concrete section or to travel to the far side of a concrete section and rebound. Damaged or low quality concrete deflects or attenuates such sound waves and can be detected by comparison of the resulting travel time with that of sound concrete. Acoustic emission devices detect the elastic waves that are generated when materials are stressed or strained beyond their elastic limits. With such devices, it is possible to "hear" the impulses from development of microcracks in overly stressed concrete. Acoustic emission equipment has been used to "hear" the occurrence of prestressing strand failure in large diameter prestressed concrete pipe. With computer assistance, several acoustic emission devices have been used not only to detect the occurrence of strand failure(s), but through triangulation, they were able to determine the location of the failure(s) (Travers, 1994).

The areas of deteriorated or damaged concrete discovered by these methods should be mapped or marked on drawings of the affected structure to provide information needed in subsequent calculations of the area and volume of concrete to be repaired and for preparation of repair specifications. Even though care is taken in these investigations, it is common to find during preparation of the concrete for repair that the actual area and volume of deteriorated concrete exceeds the original estimate. For this reason, it is usually a good idea to increase the computed quantity estimates by 15 to 25 percent to cover anticipated overruns.

6. Evaluate the Need to Repair.—Not all damaged concrete requires immediate repair. Many factors need consideration before the decision to perform repairs can be made. Obviously, repair is required if the damage affects the safety or safe operation of the structure. Similarly, repairs should be performed if the deterioration has reached a state, or is progressing at a rate, such that future serviceability of the structure will be reduced. Most concrete damage, however, progresses slowly, and several options are usually available if the deterioration is detected early. With early detection, it may be possible to arrest the rate of deterioration using maintenance procedures. Even if repair is required, early detection of damage will allow orderly budgeting of funds to pay the costs of repair.

Some types of concrete deterioration can simply be ignored. Cracking due to drying shrinkage and freezing and thawing deterioration is common on the downstream face of many older western dams. These types of damage are unsightly, but repair can seldom be justified for other than cosmetic purposes. It should be anticipated that such repairs might be more unsightly and of lower durability than the existing concrete. Conversely, structural cracks due to foundation settlement and freezing and thawing deterioration to the walls or floor of a spillway will usually require repair, if not immediately, at some point in the future. Figure 3 shows freezing and thawing damage to the face of a dam that does not require repair for safe operation of the structure. Figure 4 shows similar damage that should have been repaired long ago. Damage caused by absorptive aggregate popouts is common on bridge deck, canal, and dam concrete (figure 5). Unless such concrete is exposed to high velocity waterflows, where the offsets caused by popouts can result in cavitation damage, repair can be ignored. Figure 6 shows damage to a spillway that appears quite serious, and repair is obviously required. This spillway, however, is constructed with a very thick slab and does not experience high velocity water flow. The repairs can be scheduled at some future date to allow an orderly process of budgeting to obtain the required funding. It should be noted, however, that proper maintenance might have eliminated the need to repair this spillway.

Selecting or scheduling the most optimum time to perform needed concrete repair should be part of the process of determining the need to repair. Except in emergencies, many irrigation structures cannot be removed from service during the water delivery season. The expense or loss of income involved with the inopportune release of reservoir water in order to lower water surface elevations to accomplish repairs may exceed the costs of the repairs by many times. If such costs exceed the value of the benefits expected from performing repairs, it might be prudent to postpone or even cancel performance of the repairs. Figure 7 shows damage on a spillway floor. This damage was initially judged to be of a nonserious nature. Closer evaluation, however, revealed that foundation material had been removed from a very large area beneath this floor slab and that immediate repair was required. Had this spillway been operated without repair during periods of high spring runoff or floodflows, extensive additional damage might have resulted.

These first steps—determining the cause of damage, evaluating the extent of damage, and evaluating the need to repair—form the basis of what is known as a condition survey. If the damage is not extensive or if only a small part of a structure is involved, the condition survey could be simply a mental exercise. If major repair or rehabilitation is required, a detailed condition survey should be performed and documented. Such a survey will consist of review of the plans, specifications, and operating parameters for the structure; determination of concrete properties; and any additional field surveys, engineering studies, or structural analysis required to fully evaluate the present and desired conditions of the structure (American Concrete Institute, 1993). The final feature of a condition survey, completed only after the above-listed items have been completed, is a list of the recommended repair methods and materials.

7. Select the Repair Method.—There is a tendency to attempt selection of repair methods/materials too early in the repair process. This should be guarded against. With insufficient information, it is very difficult to make proper, economical, and successful selections. Once the above three steps of the repair process have been completed, or upon completion of a detailed condition survey, the selection of proper repair methods and materials usually becomes very easy. These steps define the types of conditions the repair must resist, the available repair construction time period, and when repairs must be accomplished. This information, in combination with data on the volume and area of concrete to be repaired, will usually determine which of the 15 standard repair materials should be used. Also, this information will determine when the standard repair materials cannot be expected to perform well and when nonstandard materials should be considered (see chapter V). Chapter IV contains a detailed discussion of each of the standard repair materials.

8. Prepare the Old Concrete for Repair.— Preparation of the old concrete for application of the repair material is of primary importance in the accomplishment of durable repairs. The

Figure 3.—Freezing and thawing deterioration to the downstream face of this dam does not require repair for safe operation of the structure.

Figure 4.—This freezing and thawing deterioration should have been repaired before it advanced to the point that wall replacement or removal is the only option.

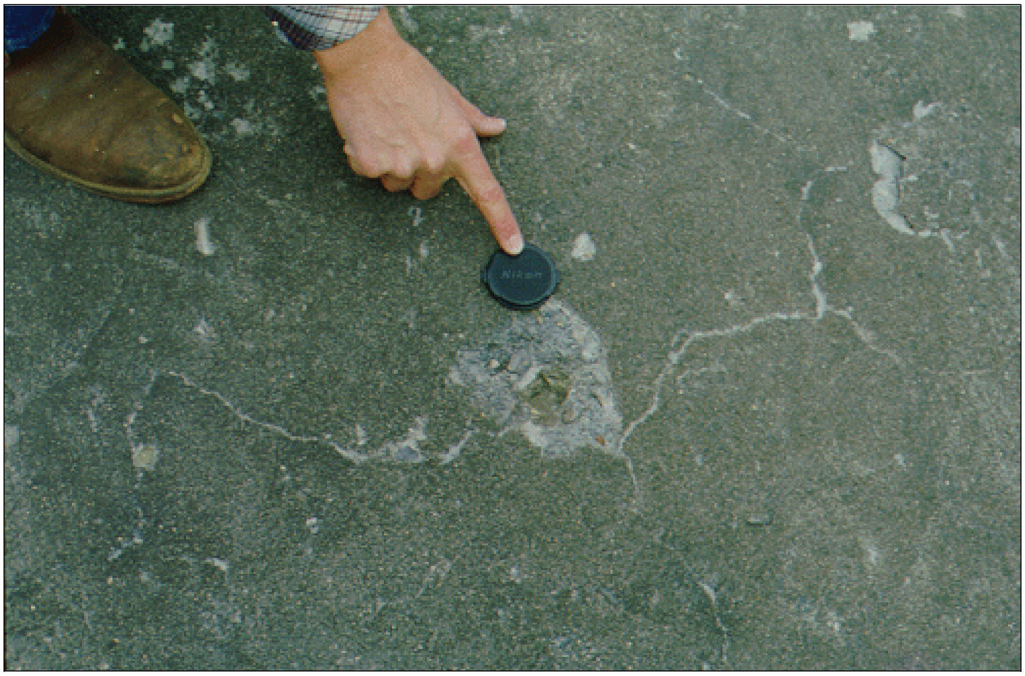

Figure 5.—Absorptive aggregate popout on spillway floor.

Figure 6.—Spillway damage requiring repairs at some future date.

Figure 7.—This concrete damage was found to be a serious threat to the structural integrity of this spillway.

very best of repair materials will give unsatisfactory performance if applied to weakened or deteriorated old concrete. The repair material must able to bond to sound concrete. It is essential that all of the unsound or deteriorated concrete be removed before new repair materials are applied.

Saw Cut Perimeters. The first step in preparing the old concrete for repair is to saw cut the perimeter of the repair area to a depth of 1 to 1.5 inches. The purpose of the saw cuts is to provide a retaining boundary against which the repair material can be compacted and consolidated. The perimeters of repairs are the locations most exposed to the effects of shrinkage, deterioration, and bond failure. Only poor compaction of repair material can be accomplished at feather edge perimeters. Such repair zones will fail quickly. For this reason feather edge perimeters to repair areas are not permitted by Reclamation's M-47 specifications. It is unnecessary to cut to the full depth of the repair, although to do so is not harmful. The saw cuts should be perpendicular to the concrete surface or tilted inward 2 to 3 degrees to provide retaining keyways that mechanically lock the repair material into the area. Tilting the saw inward more than 3 degrees may result in weak top corners in the old concrete and should be avoided. The saw cuts should never be beveled outward.

It is usually false economy to try to closely follow the shape of the repair area with a multitude of short saw cuts as seen at the bottom of figure 8. The cost of sawing such a shape most likely will exceed the cost of

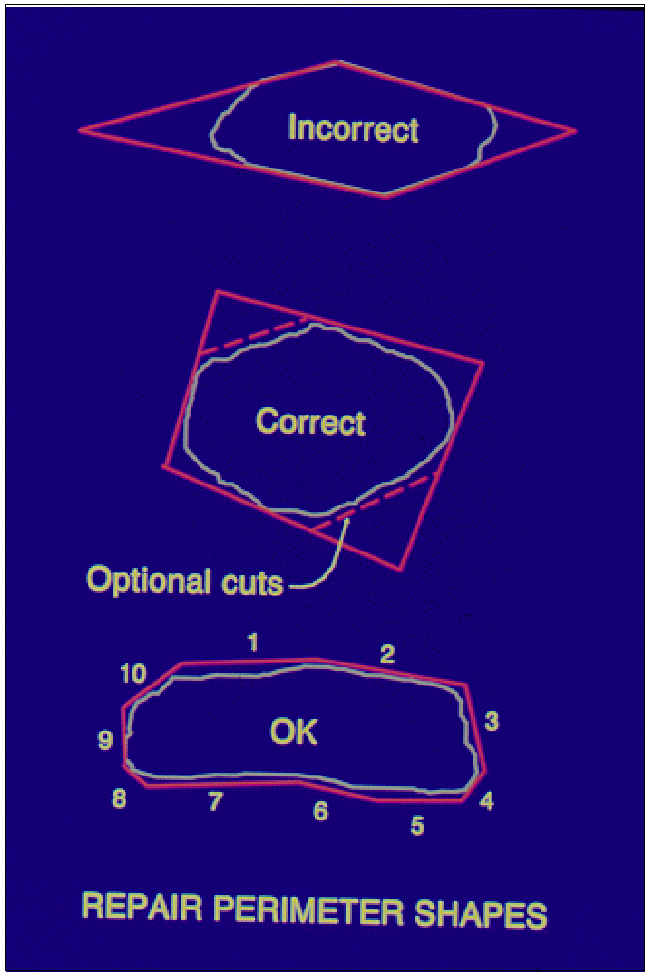

Figure 8.—Saw cut patterns for the perimeters of repair areas.

increased repair area, and the resulting repair may be less attractive than those having simple rectangular shapes. Saw cuts should not meet in acute angles as shown at the top of figure 8. It is very difficult to compact repair material into such sharp corners. The saw cut perimeters should have rounded corners, as seen in figure 9, whenever reasonable. Rounded corners cannot be cut with a circular concrete saw, but the cuts can be stopped short of the intersection and rounded using a jackhammer or bush hammer carefully held in a vertical orientation. It should be noted that intersections cannot be cut with a circular saw without the cuts extending outside the intersection. These cut extensions often serve as sources of cracking in some repair materials. Once the perimeters have been cut, the deteriorated concrete is removed using methods discussed in following paragraphs.

Concrete Removal. All deteriorated or damaged concrete must be removed from the repair area to provide sound concrete for the repair material to bond to. It is always false economy to attempt to save time or money by shortchanging the removal of deteriorated concrete. Whenever possible, the first choice of concrete removal technique should be high pressure (8,000 to 15,000 pounds per square inch [psi]) hydroblasting or hydrodemolition. These techniques have the advantage of removing the unsound concrete while leaving high quality concrete in place. They have a further advantage in that they do not leave microfractured surfaces on the old concrete. Impact removal techniques, such as bush-hammering, scrabbling, or jackhammering, can leave surfaces containing a multitude of microfractures which seriously reduce the bond of the repair material to the existing

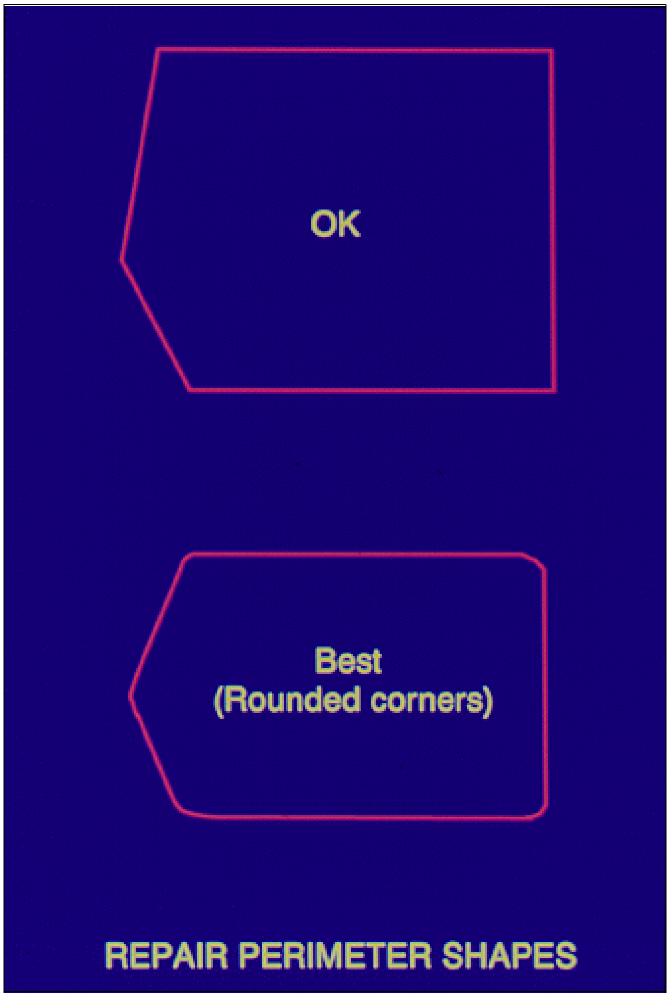

Figure 9.—Corners of repair areas should be rounded whenever possible.

concrete. Subsequent removal of the microfractured surface by hydroblasting, shot blasting, or by wet or dry sandblasting is required by Reclamation's M-47 specifications if impact removal techniques are used. A disadvantage of the high pressure water blasting techniques is that the waste water and debris must be handled in an environmentally acceptable manner as prescribed by local regulations.

Impact concrete removal techniques, such as jackhammering for large jobs and bush-hammering for smaller areas, have been used for many years. These removal procedures are quick and economical, but it should be kept in mind that the costs of subsequent removal of the microfractured surfaces resulting from these techniques must be included when comparing the costs of these techniques to the costs of high pressure water blasting. The maximum size of jackhammers should usually be limited to 60 pounds. The larger jackhammers remove concrete at a high rate but are more likely to damage surrounding sound concrete. The larger hammers can impact and loosen the bond of concrete to reinforcing steel for quite some distance away from the point of impact. Pointed hammer bits, which are more likely to break the concrete cleanly rather than to pulverize it, should be used to reduce the occurrence of surface microfracturing.

Shallow surface deterioration (usually less than 1/2 inch deep) is best removed with shot blasting (figure 10) or dry or wet sand-blasting. Shot blasting equipment is highly efficient and usually includes some type of vacuum pickup of

Figure 10 – Shot blasting equipment used to remove shallow concrete deterioration

the resulting dust and debris. The use of such equipment is much more environmentally acceptable than dry sand blasting. The need for removal of such shallow depths of deteriorated concrete is seldom encountered in Reclamation repairs other than for removal of microfractured surfaces or for cosmetic surface cleaning. Shallow deterioration to concrete surfaces can also be removed with tools known as scrabblers (figure 11). These tools usually have multiple bits (figure 12) which pound and pulverize the concrete surfaces in the removal process. Their use greatly multiplies the micro fractures in the remaining concrete surfaces. Extensive high pressure water, sand, or shot blasting efforts are then needed to remove the resulting damaged surfaces. Such efforts are seldom attained under field conditions. For this reason, Reclamation's M-47 specifications prohibit use of scrabblers for concrete removal.

Reinforcing Steel Preparation. Reinforcing steel exposed during concrete removal requires special treatment. As a minimum, all scale, rust, corrosion, and bonded concrete must be removed by wire brushing or high pressure water or sand blasting. It is not necessary to clean the steel to white metal condition, just to remove all the loose or poorly bonded debris that would affect bond between the repair material and the reinforcing steel. If corrosion has reduced the cross section of the steel to less than 75 per- cent of its original diameter, the affected bars should be removed and replaced in accordance with section 12.14 of American Concrete Institute (ACI) 318 (ACI, 1992). Steel exposed more than one-third of its perimeter circumference should be sufficiently exposed to provide a 1-inch minimum clearance between the steel and the concrete. Figure 13 shows the correct concrete removal and preparation for repairing a delamination occurring at the top mat of reinforcing steel of a concrete slab. Figure 14 shows correct preparation of a concrete defect that extends entirely through a wall. Figure 15 shows a properly prepared shallow repair area on a highway bridge deck.

Maintenance of Prepared Area. After the repair area has been prepared, it must be maintained in a clean condition and protected

Figure 11.—Scrabbler equipment used to remove shallow concrete deterioration.

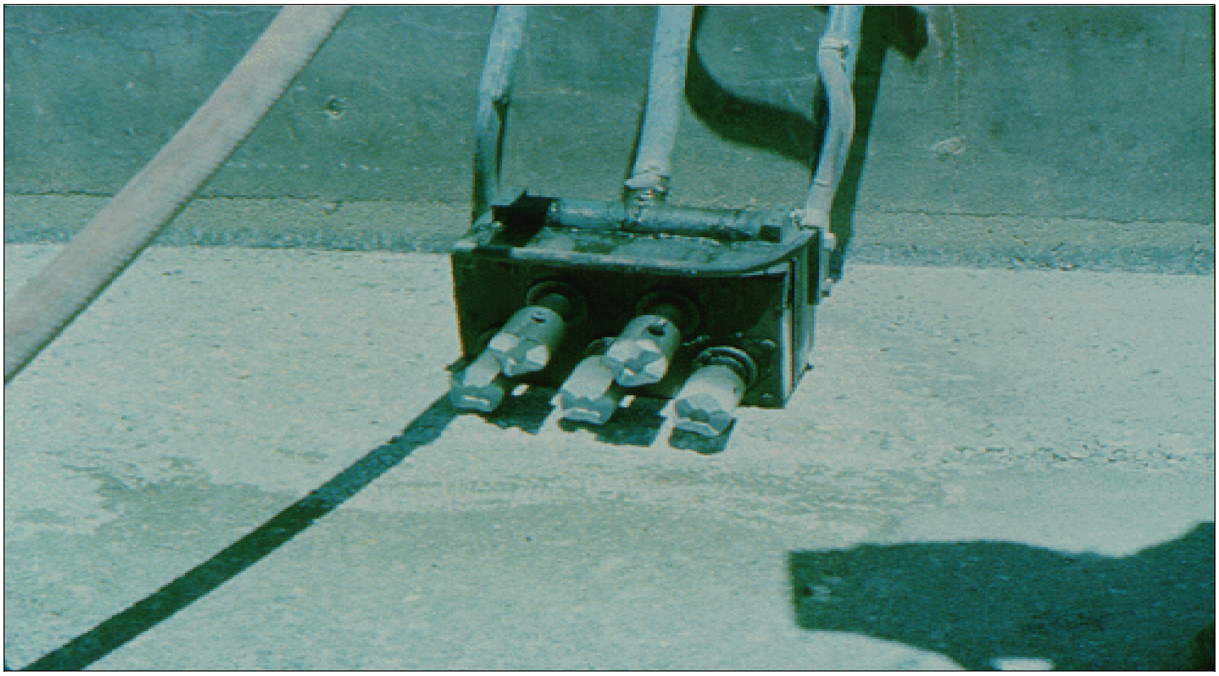

Figure 12.—Multiple bits on the head of a scrabbler pound and pulverize the concrete surface during the removal process.

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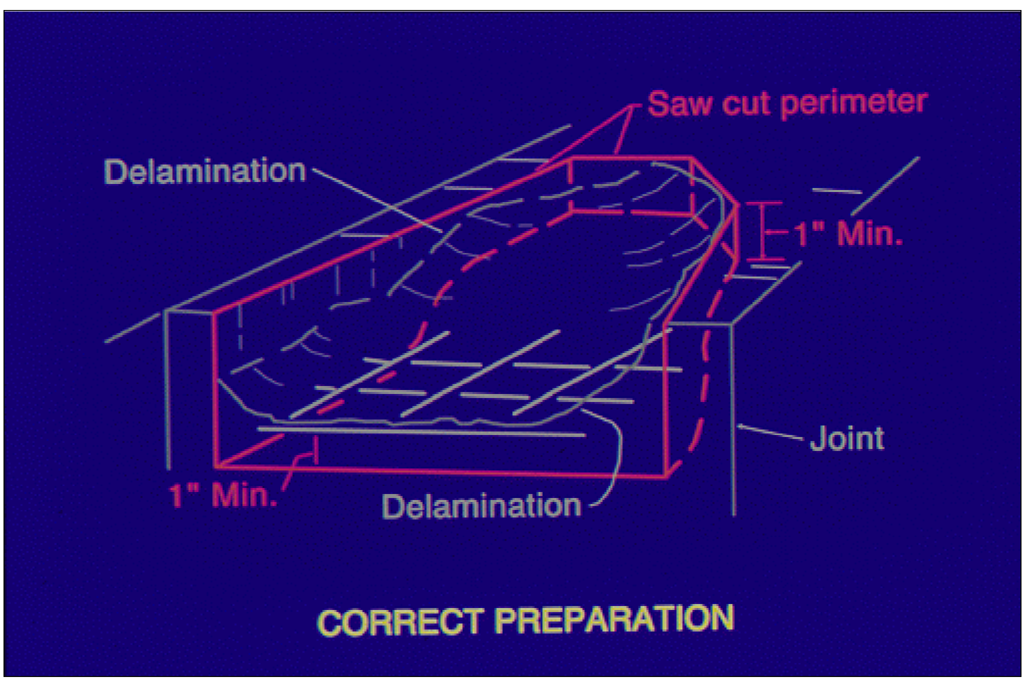

Figure 13.—Correct preparation of a concrete delamination. Perimeter has been saw cut to a minimum depth of 1 inch, and concrete has been removed to at least 1 inch beneath exposed reinforcing steel.

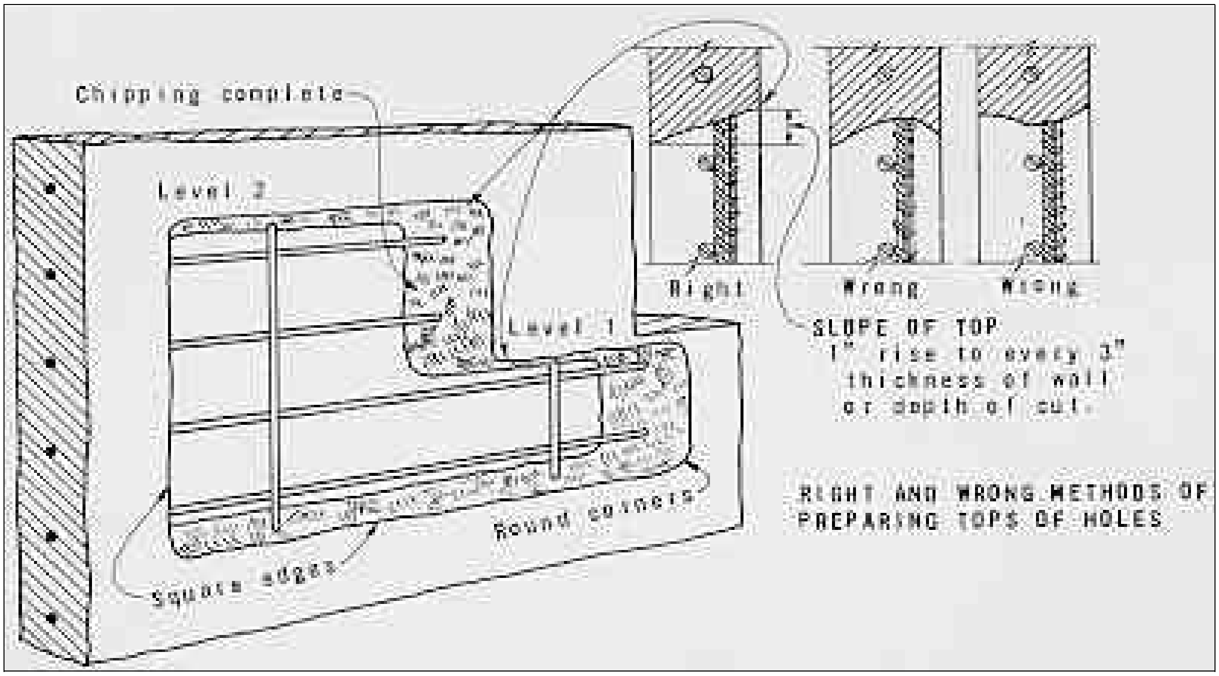

Figure 14.—Preparation of a concrete deterioration that extends completely through a concrete wall.

Figure 15.—Preparation of a shallow defect on a highway bridge deck.

from damage until the repair materials can be placed and cured. In hot climates, this might involve providing shade to keep the concrete cool, thereby reducing rapid hydration or hardening. If winter conditions exist, steps need to be taken to provide sufficient insulation and/or heat to prevent the repair area from being covered with snow, ice, or snowmelt water. It should be remembered that repair activities can also contaminate or damage a properly prepared site. Workmen placing repair materials in one area of a repair often track mud, debris, cement dust, or concrete into an adjacent repair area. Once deposited on a prepared surface, this material will serve as a bond breaker if not cleaned up before the new repair material is placed. Repair contractors should be required to repeat preparation if a repair area is allowed to become damaged or contaminated. The prepared concrete should be kept wet or dry, depending upon the repair material to be used. Surfaces that will receive polymer concrete or epoxy-bonded materials should be kept as dry as possible. Some epoxies will bond to wet concrete, but they always bond better to dry concrete. Surfaces that will be repaired with cementitious material should be in a saturated surface dry (SSD) condition immediately prior to material application. This condition is achieved by soaking the surfaces with water for 2 to 24 hours just before repair application. Immediately before material application, the repair surfaces should be blown free of water, using compressed air. The SSD condition prevents the old concrete from absorbing mix water from the repair material and promotes development of adequate bond strength in the repair material. The presence of free water on the repair surfaces during application of the repair material must be avoided whenever practicable.

9. Apply the Repair Method.—There are 15 different standard concrete repair methods/materials in Reclamation's M-47 specification. Each of these materials has uniquely different requirements for successful application. These requirements and application procedures are discussed at length in chapter IV of this guide.

10. Cure the Repair Properly.—All of the standard repair materials, with the exception of some of the resinous systems, require proper curing procedures. Curing is usually the final step of the repair process, followed only by cleanup and demobilization, and it is somewhat common to find that the curing step has been shortened, performed haphazardly, or eliminated entirely as a result of rushing to leave the job or for the sake of perceived economies. It should be understood that proper curing does not represent unnecessary costs. Rather, it represents a sound investment in long-term insurance. Inadequate or improper curing can result in significant loss of money. At best, improper curing will reduce the service life of the repairs. More likely, inadequate or improper curing will result in the necessity to remove and replace the repairs. The costs of the original repair are, thus, completely lost, and the costs of the replacement repair will be greater because the replacement repairs will be larger and must include the costs of removal of the failed repair material. The curing requirements for each of the 15 standard repair materials are discussed in chapter IV.

Chapter III

Causes of Damage to Concrete

The more common causes of damage to Reclamation concrete are discussed in this chapter. The discussion for each cause of damage consists of (1) a description of the cause and how it damages concrete and (2) a discussion and/or listing of appropriate methods/materials to repair that particular type of concrete damage. The format for the text of this chapter was chosen in recognition of the importance of first determining the cause(s) of damage to concrete before trying to select the repair method. It is expected that the full discussion of the selected repair method, as found in chapter IV, will be consulted prior to performance of the work.

11. Excess Concrete Mix Water.—The use of excessive water in concrete mixtures is the single most common cause of damage to concrete. Excessive water reduces strength, increases curing and drying shrinkage, increases porosity, increases creep, and reduces the abrasion resistance of concrete. Figure 16 shows the cumulative effects of water-cement ratio on the durability of concrete. In this figure, high durability is associated with low water-cement ratio and the use of entrained air.

Damage caused by excessive mix water can be difficult to correctly diagnose because it is usually masked by damage from other causes. Freezing and thawing cracking, abrasion erosion deterioration, or drying shrinkage cracking, for example, is often blamed for damage to concrete when, in reality, excessive mix water caused the low durability that allowed these other causes to attack the concrete. During petrographic examination, extreme cases of excessive mix water in hardened concrete can sometimes be detected by the presence of bleed water channels or water pockets under large aggregate. More commonly, examination of the batch sheets, mix records, and field inspection reports will provide confirmation of the use of excessive mix water in damaged concrete. It should be recognized, however, that water added to transit truck mixes at the construction site or applied to concrete surfaces during finishing operations often goes undocumented.

The only permanent repair of concrete damaged by excessive mix water is removal and replacement. However, depending on the extent and nature of damage, a number of maintenance or repair methods can be useful in extending the service life of such concrete. If the damage is detected early and is shallow (less than 1.5 inches deep), application of concrete sealing compounds, such as the high solids content (greater than 15 percent) oligomeric alkyl-alkoxy siloxane or silane systems (section 38) or the high molecular weight methacrylic monomer system (section 35), will reduce water penetration and improve resistance to freeze-thaw spalling and deterioration. Such systems require reap-plication at 5- to 10-year intervals. Epoxy- bonded replacement concrete (section 31) can be used to repair damage that extends between 1.5 and 6 inches into the concrete, and replacement concrete (section 29) can be used to repair damage 6 inches deep or deeper.

12. Faulty Design.—Design faults can create many types of concrete damage. Discussion of all the types of damage that can result from faulty design is beyond the scope of this guide. However, one type of design fault that is somewhat common is positioning em-bedded metal such as electrical conduits or outlet boxes too near the exterior surfaces of concrete structures. Cracks form in the concrete over and around such metal features and allow accelerated freeze-thaw deterioration to occur. Bases of handrails or guardrails

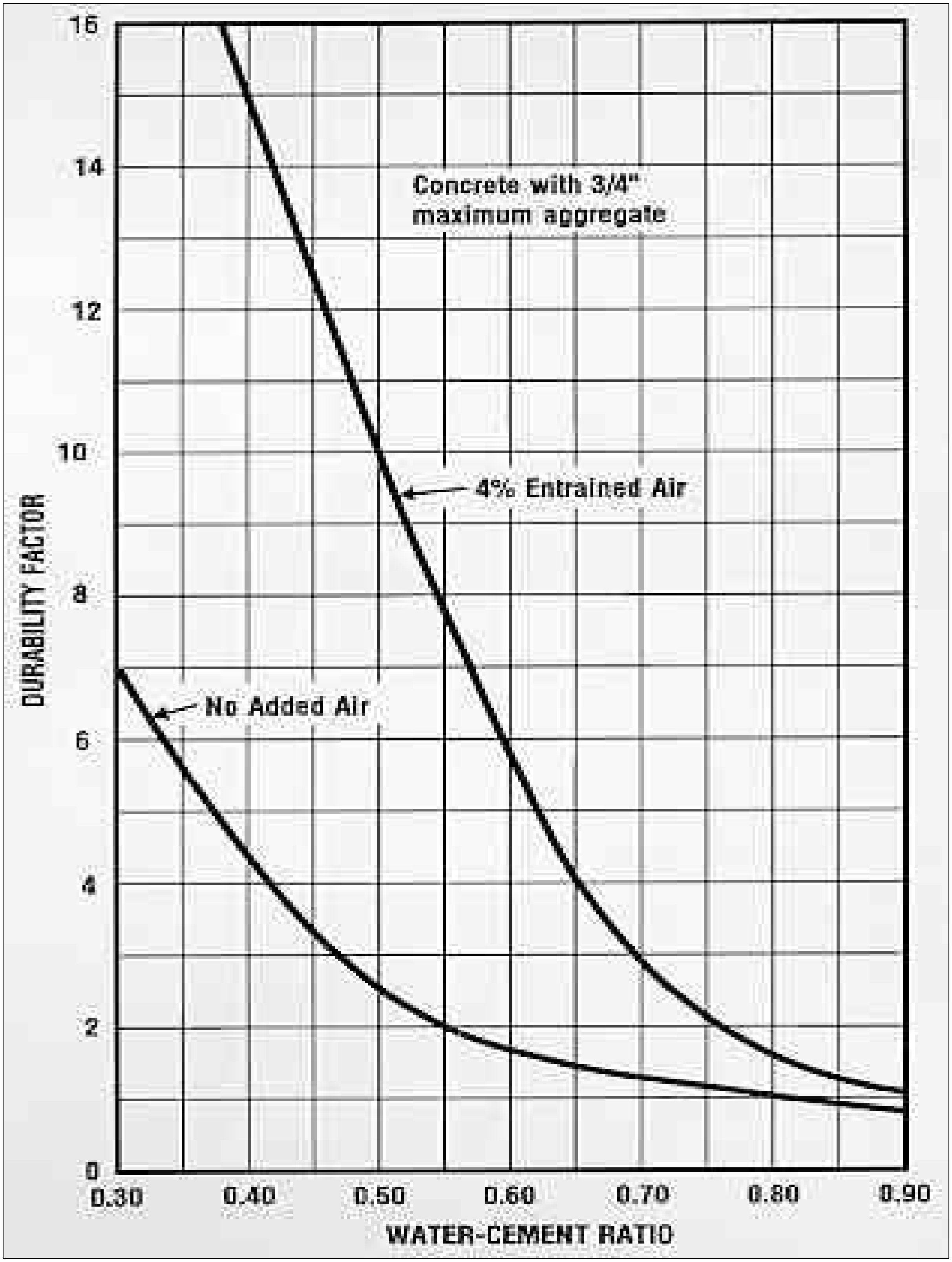

Figure 16.—Relation between durability and water-cement ratio for air entrained and nonair entrained concrete.

are placed too near the exterior corners of walls, walkways, and parapets with similar results. These bases or intrusions into the concrete expand and contract with temperature changes at a rate different from the concrete. Tensile stresses, created in the concrete by expanding metal, cause cracking and subsequent freeze-thaw damage. Long guardrails or handrails can create another problem. The pipe used for such rails also undergoes thermal expansion and contraction. If sufficient slip joints are not provided in the rails, the expansion and contraction cause cracking at the points where the rail attachment bases enter the concrete. This cracking also allows accelerated damage to the concrete from freezing and thawing.

Insufficient concrete cover over reinforcing steel is a common cause of damage to highway bridge structures. This can also be a problem in hydroelectric and irrigation structures. Reclamation usually requires a minimum of 3 inches of concrete cover over reinforcing steel, but in corrosive environments, this can be insufficient. Concrete exposed to the corrosive effects of sulfates, acids, or chlorides should have a minimum of 4 inches of cover to protect the reinforcing steel. Insufficient cover allows corrosion of the reinforcing steel to begin. The iron oxide byproducts of this corrosion require more space in the concrete than the reinforcing steel and result in cracking and delaminating in the concrete.

Failure to provide adequate contraction joints or failure to make expansion joints wide enough to accommodate temperature expansion in concrete slabs will result in damage. Concrete with inadequate contraction joints will crack and make a joint wherever a joint was needed but not pro-vided. Unfortunately, such cracks will not be as visually attractive as a formed or sawed joint. Formation of the cracks relieves the tensile stresses and, though unsightly, seldom requires repair. Concrete slabs constructed with insufficient or too narrow expansion joints can cause serious damage to bridge deck surfaces, dam roadways, and the floors of long, steeply sloping, south facing spillways. Such concrete experiences large daily and seasonal temperature changes resulting from solar radiation. The resulting concrete expansion is greater in the top surfaces of the slabs, where the concrete temperatures are higher, and less in the cooler bottom edges. Such expansion can cause the upper portions of concrete in adjacent slabs to butt against one another at the joints between the slabs. The only possible direction of relief movement in such slabs is upward, which causes delaminations to form in the concrete, starting at the joints and extending an inch or two back into the slab. These delaminations are commonly located at the top mat of reinforcing steel. In temperate climates, the formation of delaminations relieves the expansion strains, and further damage will usually cease. In cold climates, however, water can enter the delaminations where it undergoes a daily cycle of freezing and thawing. This causes the delaminations to grow and extend as much as 3 to 5 feet away from the joint. Figure 17 is an exaggerated example of such damage.

Repair of damage caused by faulty design is futile until the design faults have been mitigated. Embedded metal features can be removed, handrails can be provided with slip joints, and guardrail attachment bases can be moved to locations with sufficient concrete to withstand the tensile forces. Mitigation of insufficient concrete cover over reinforcing steel is very difficult, but repair materials resistant to those particular types of corrosion can be selected for the repair. Repairs can also be protected by concrete sealing compounds or coatings to reduce water penetration. Slabs containing inadequate expansion joints can be saw cut to increase the number of joints and/or to widen the joints to provide sufficient room for the expected thermal expansion.

Damage caused by design faults can most likely be repaired using replacement concrete (section 29), epoxy-bonded replacement concrete (section 31), or epoxy-bonded epoxy mortar (section 30).

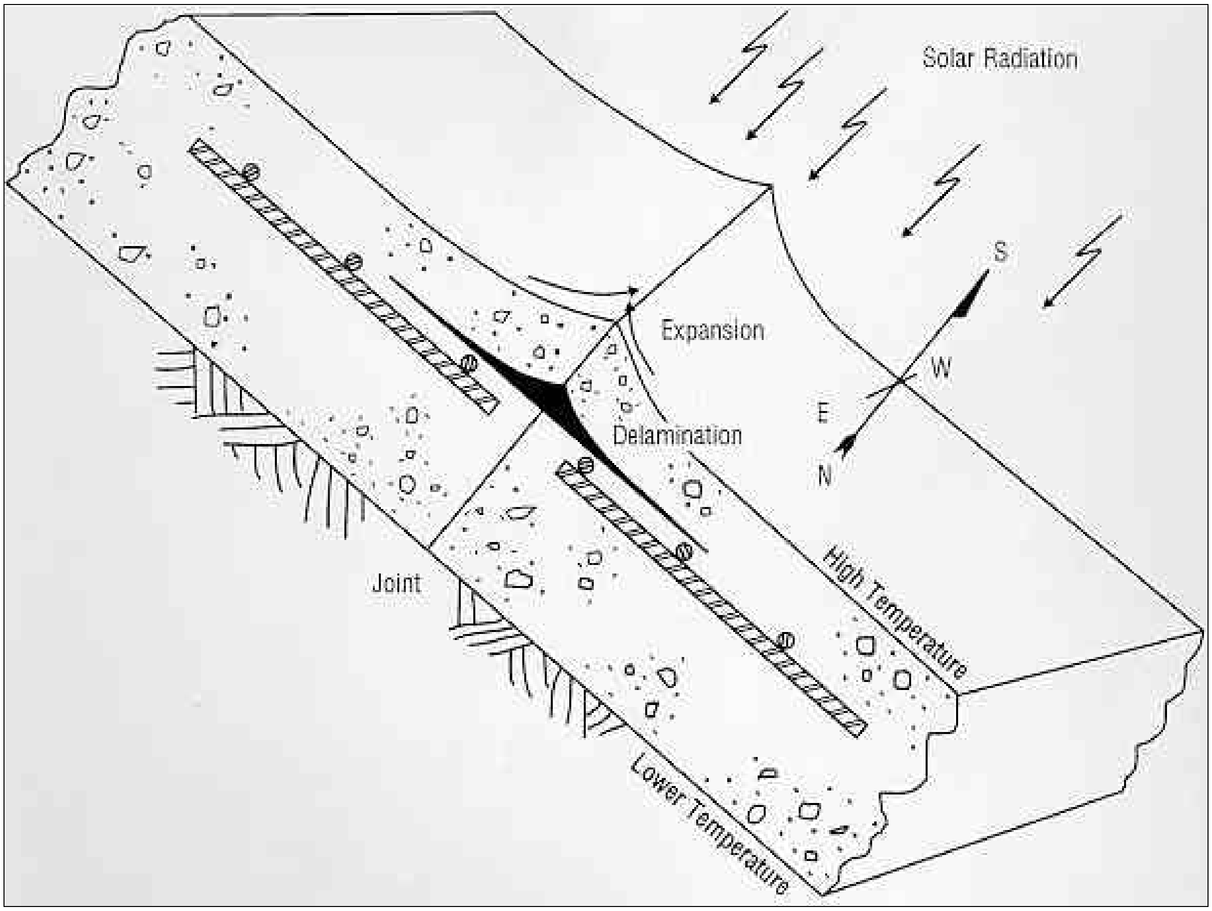

Figure 17.—Delamination caused by solar expansion.

13. Construction Defects.—Some of the more common types of damage to concrete caused by construction defects are rock pockets and honeycombing, form failures, dimensional errors, and finishing defects.

Honeycomb and rock pockets are areas of concrete where voids are left due to failure of the cement mortar to fill the spaces around and among coarse aggregate particles. These defects, if minor, can be repaired with cement mortar (section 25) if less than 24 hours has passed since form removal. If repair is delayed longer than 24 hours after form removal, or if the rock pocket is extensive, the area must be prepared and the defective concrete must be removed and replaced with dry pack (section 26), epoxy-bonded replacement concrete (section 31), or replacement concrete (section 29). Some minor defects resulting from form movement or failure can be repaired with surface grinding (section 24). More likely, the resulting defect is either simply accepted by the owner, or the contractor is required to remove the defective concrete and reconstruct that portion of the structure.

There are many opportunities to create dimensional errors in concrete construction. Whenever possible, it usually is best to accept the resulting deficiency rather than attempt to repair it. If the nature of the deficiency is such that it cannot be accepted, then complete removal and reconstruction is probably the best course of action. Occasionally, dimensional errors can be corrected by removing the defective concrete and replacing it with epoxy-bonded concrete or replacement concrete.

Finishing defects usually involve overfinishing or the addition of water and/or cement to the surface during the finishing procedures. In each instance, the resulting surface is porous and permeable and has low durability. Poorly finished surfaces exhibit surface spalling early in their service life. Repair of surface spalling involves removal of the weakened concrete and replacement with epoxy-bonded concrete (section 31). If the deterioration is detected early, the service life of the surface can be extended through the use of concrete sealing compounds (sections 35 and 38).

14. Sulfate Deterioration.—Sodium, magnesium, and calcium sulfates are salts commonly found in the alkali soils and groundwaters of the Western United States. These sulfates react chemically with the hydrated lime and hydrated aluminate in cement paste and form calcium sulfate and calcium sulfoaluminate. The volume of these reaction byproducts is greater than the volume of the cement paste from which they are formed, causing disruption of the concrete from expansion. Type V portland cement, which has a low calcium aluminate content, is highly resistant to sulfate reaction and attack and should be specified when it is recognized that concrete must be exposed to soil and groundwater sulfates. See table 2 of the *Concrete Manual* (Bureau of Reclamation, 1975) for guidance on materials and mixture proportions for concretes exposed to sulfate environments.

Concrete that is undergoing active deterioration and damage due to sulfate exposure can sometimes be helped by application of a thin polymer concrete overlay (section 33) or concrete sealing compounds (sections 35 and 38). Alternate wetting and drying cycles accelerate sulfate deterioration, and some slowing of the rate of deterioration can be accomplished by interrupting the cyclic wetting and drying. Procedures for eliminating or removing waterborne sulfates are also helpful if this is the source of the sulfates. Otherwise, the deteriorating concrete should be monitored for removal and replacement with concrete constructed of type V cement, when appropriate.

15. Alkali-Aggregate Reaction.—Certain types of sand and aggregate, such as opal, chert, and flint, or volcanics with high silica content, are reactive with the calcium, sodium, and potassium hydroxide alkalies in portland cement concrete. These reactions, though observed and studied for more than 50 years (Bureau of Reclamation, 1942), remain poorly defined and little understood. Some concrete containing alkali reactive aggregate shows immediate evidence of destructive expansion and deterioration. Other concrete might remain undisturbed for many years. Petrographic examination of reactive concrete shows that a gel is formed around the reactive aggregate. This gel undergoes extensive expansion in the presence of water or water vapor (a relative humidity of 80 to 85 percent is all the water required), creating tension cracks around the aggregate and expansion of the concrete (figure 18). If unconfined, the expansion within the concrete is first apparent by pattern cracking on the surface. Usually, some type of whitish exudation will be evident in and around the cracked concrete. In extreme instances, these cracks have opened 1.5 to 2 inches (figure 19). It is common for such expansion to cause significant offsets in the concrete and binding or seizure of control gates on dams. In large concrete structures, alkali-aggregate reaction may occur only in certain areas of the structure. Until it is recognized that multiple aggregate sources are commonly used to construct large concrete structures, this might be confusing. Only portions of the structure constructed with concrete containing alkali reactive sand and/or aggregate will exhibit expansion due to alkali-aggregate reaction. This situation presently exists at Minidoka Dam (Stark and DePuy, 1995), Stewart Mountain Dam, Coolidge Dam, Friant Dam, and Seminoe Dam.

In new construction, low alkali portland cements and fly ash pozzolan can be used to

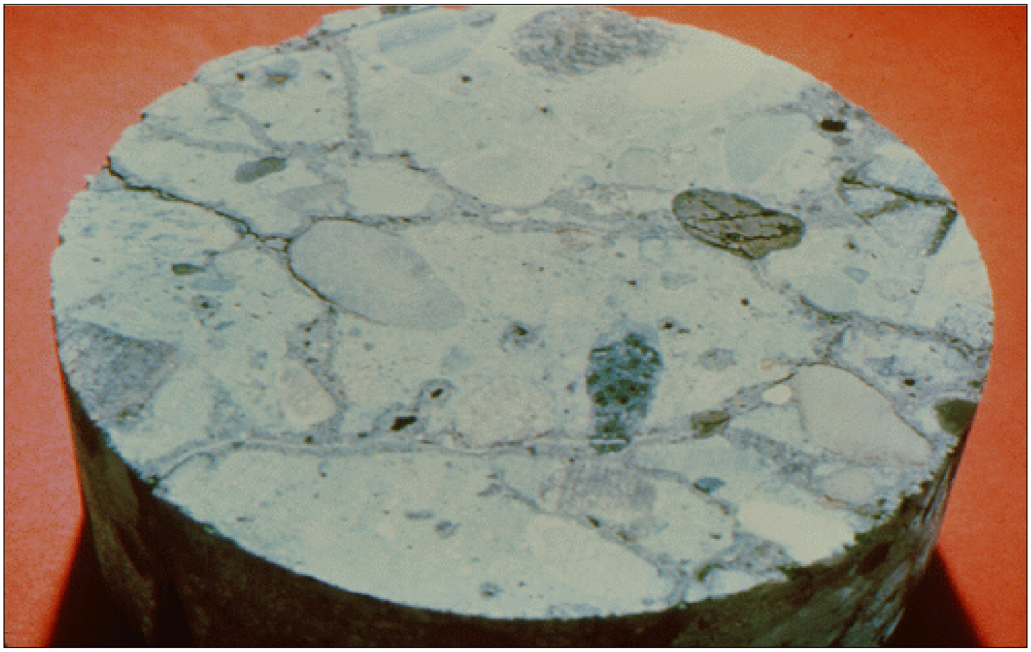

Figure 18.—Gel resulting from alkali-aggregate reaction causes expansion and tension cracks in a concrete core.

eliminate or greatly reduce the deterioration of reactive aggregates. In existing concrete structures, deterioration due to reactive aggregate is virtually impossible to mediate. There are no proven methods of eliminating the deterioration of alkali-aggregate reaction, although the rate of expansion can sometimes be reduced by taking steps to maintain the concrete in as dry a condition as possible. It is usually futile to attempt repair of concrete actively undergoing alkali-aggregate reaction. The continuing expansion within the concrete will simply disrupt and destroy the repair material. Structures undergoing active deterioration should be monitored for rate of expansion and movement, and only the repairs necessary to maintain safe operation of the facility should be made. The binding gates of several dams have been relieved and returned to operation by using wire saws to make expansion relief cuts in the concrete on either side of the binding gates. The cuts were subsequently sealed to water leakage using polyurethane resin injection techniques (section 34). With continuing expansion of the concrete, such relief cuts may have to be repeated several times. In many structures, the expansion and movement associated with reactive aggregate slows down and ceases when all the alkali components are consumed by the reactions. Once the expansion ceases, repairs can be performed to rehabilitate and restore the structure to full operation and serviceability. However, it should be anticipated that, ultimately, it may be necessary to replace structures undergoing alkali-aggregate deterioration. Such was the case with the 1975 replacement of Reclamation's American Falls Dam in Idaho. This dam was constructed in 1927 and replaced after extensive studies conducted by Reclamation's Denver concrete laboratories revealed that it had been severely damaged by alkali-aggregate reaction.

16. Deterioration Caused by Cyclic Freezing and Thawing.—Freeze-thaw deterioration is a common cause of damage to concrete constructed in the colder climates. For freeze-thaw damage to occur, the following conditions must exist:

a. The concrete must undergo cyclic freezing and thawing.

Figure 19.—Severe cracking caused by alkali-aggregate reaction.

b. The pores in the concrete, during freezing, must be nearly saturated with water (more than 90 percent of saturation).

Water experiences about 15 percent volumetric expansion during freezing. If the pores and capillaries in concrete are nearly saturated during freezing, the expansion exerts tensile forces that fracture the cement mortar matrix. This deterioration occurs from the outer surfaces inward in almost a layering manner. The rate of progression of freeze-thaw deterioration depends on the number of cycles of freezing and thawing, the degree of saturation during freezing, the porosity of the concrete, and the exposure conditions. The tops of walls exposed to snowmelt or water spray, horizontal slabs exposed to water, and vertical walls at the water line are the locations most commonly damaged by freeze-thaw deterioration. If such concrete has a southern exposure, it will experience daily cycles of freezing during the night and thawing during the morning. Conversely, concrete with a northern exposure may only experience one cycle of freezing and thawing each winter, a far less damaging condition. Figures 20 and 21 show typical examples of freeze-thaw deterioration.

Another type of deterioration caused by cycles of freezing and thawing is known as D-cracking. In this instance, the expansion occurs in low quality, absorptive, coarse aggregate instead of in the cement mortar matrix. D-cracking is most commonly seen at the exposed corners of walls or slabs formed by joints. A series of roughly parallel cracks exuding calcite usually cuts across the corners of such damage (figure 22).

In 1942, Reclamation began specifying the use of air entraining admixtures (AEA) in concrete to protect concrete from freezing and thawing damage. Concrete structures built prior to that date did not contain AEA. Angostura Dam, started in 1946, was the first Reclamation Dam constructed with specifications requiring the use of AEA (Price, 1981). This type of admixture produces small air bubbles in the concrete matrix that provide space for water expansion during freezing. If the proper AEA, at the correct concentration, is properly mixed into high quality fresh concrete, there should be very little damage resulting from cyclic freezing and thawing except in very severe climates. Accordingly, if freezing and thawing damage is suspected in modern concrete, investigations should be performed to determine why the AEA was not effective. Except in cases of extremely cold and wet exposure, modern concrete exhibiting freeze-thaw damage has most likely suffered low durability from some other cause (see section 23).

Damage caused by cyclic freezing and thawing of concrete occurs only when the concrete is nearly saturated. Successful mitigation of freeze-thaw deterioration, therefore, involves reducing or eliminating the cycles of freezing and thawing or reducing absorption of water into the concrete. It usually is not practical to protect or insulate concrete from cycles of freezing and thawing temperatures, but concrete sealing compounds (sections 35 and 38) can be applied to exposed concrete surfaces to prevent or reduce water absorption. The sealing compounds are not effective in protecting inundated concrete, but they can provide protection to concrete exposed to rain, windblown spray, or snow melt water.

Repair of concrete damaged by freeze-thaw deterioration is most often accomplished with replacement concrete (section 29) if the damage is 6 inches or deeper, or with epoxy- bonded replacement concrete (section 31) or polymer concrete (section 32) if the damage is between 1.5 and 6 inches deep. The replacement concretes must, of course, contain AEA. Attempted repair of spalls or shallow freeze-thaw deterioration less than 1.5 inches deep is discouraged. To date, no generic or proprietary repair material tested in the Denver laboratories has been found fully suitable for such shallow repairs.

17. Abrasion-Erosion Damage.—Concrete structures that transport water containing silt,

Figure 20.—Freezing and thawing deterioration on small irrigation gate structure.

Figure 21.—Freezing and thawing deterioration on spillway concrete.

Figure 22.—D-cracking type of freezing and thawing deterioration.

sand, and rock or water at high velocities are subject to abrasion damage. Dam stilling basins experience abrasion damage if the flows do not sweep debris from the basins. Some stilling basins have faulty flow patterns that cause downstream sand and rock to be pulled upstream into the basins. This material is retained in the basins where it produces significant damage during periods of high flow (figure 23). Abrasion damage results from the grinding action of silt, sand, and rock. Concrete surfaces damaged in this way usually have a polished appearance (figure 24). The coarse aggregate often is exposed and somewhat polished due to the action of the silt and sand on the cement mortar matrix. Figure 25 shows an early stage of abrasion or, possibly, erosion damage to a stilling basin wall. The extent of abrasion-erosion damage is a function of so many variables—duration of exposure, shape of the concrete surfaces, flow velocity and pattern, flow direction, and aggregate loading—that it is difficult to develop general theories to predict concrete performance under these conditions. Consequently, hydraulic model studies are often required to define the flow conditions and patterns that exist in damaged basins and to evaluate required modifications. If the conditions that caused abrasion-erosion damage are not addressed, the best repair materials will suffer damage and short service life.

It is generally understood that high quality concrete is far more resistant to abrasion damage than low quality concrete, and a number of studies (Smoak, 1991) clearly indicate that the resistance of concrete increases as the compressive strength of the concrete increases.

Abrasion damage is best repaired with silica fume concrete (section 37) or polymer concrete (section 32). These materials have shown the highest resistance to abrasion damage in laboratory and field tests. If the damage does not extend behind reinforcing steel or at least 6 inches into the concrete, the silica fume concrete should be placed over a fresh epoxy bond coat. Figure 26 shows the application of silica fume concrete to an area of abrasion, erosion, and freeze-thaw damage on the floor of

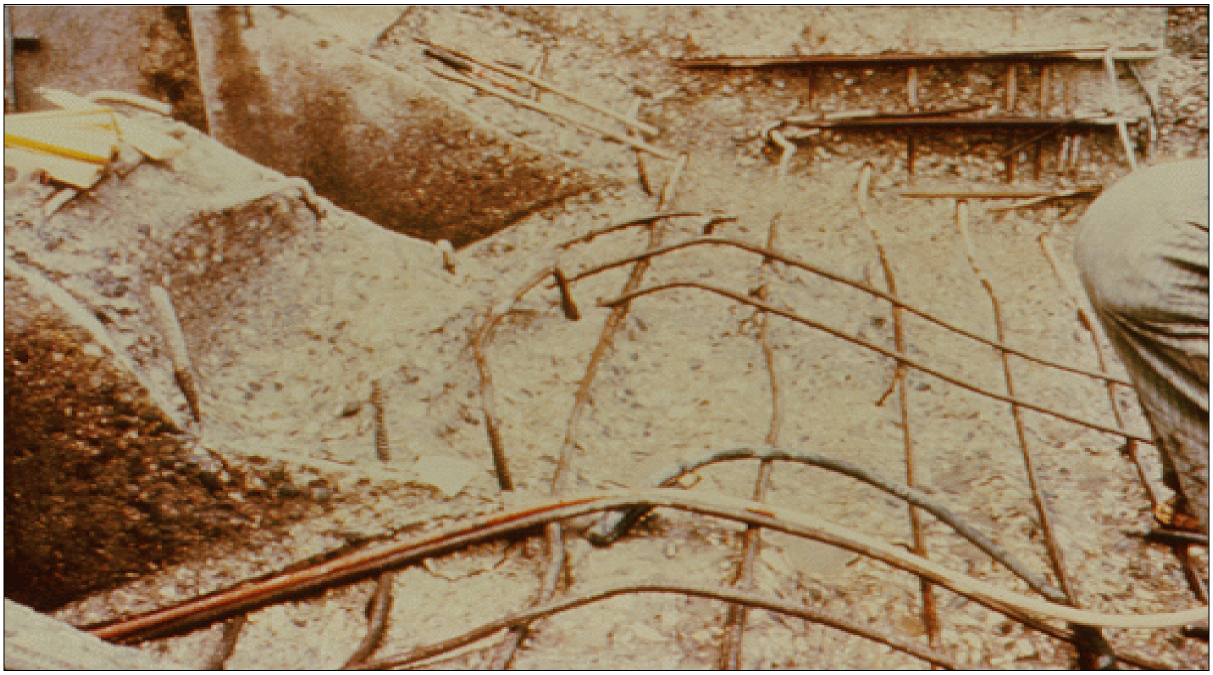

Figure 23.—Abrasion-erosion damage in a concrete stilling basin.

Figure 24.—Abrasion-erosion damage caused by sand or silt.

Figure 25.—Early stages of abrasion-erosion damage.

the Vallecito Dam spillway.

18. Cavitation Damage.—Cavitation damage occurs when high velocity waterflows encounter discontinuities on the flow surface. Discontinuities in the flow path cause the water to lift off the flow surface, creating negative pressure zones and resulting bubbles of water vapor. These bubbles travel downstream and collapse. If the bubbles collapse against a concrete surface, a zone of very high pressure impact occurs over an infinitely small area of the surface. Such high impacts can remove particles of concrete, forming another discontinuity which then can create more extensive cavitation damage. Figure 27 shows the classic "Christmas tree" pattern of cavitation damage that occurred in a large concrete-lined tunnel at Glen Canyon Dam during the flood releases of 1982. In this instance, cavitation damage extended entirely through the concrete tunnel lining and some 40 feet into foundation rock (figure 28).

Cavitation damage is common on and around water control gates and gate frames. Very high velocity flows occur when control gates are first being opened or at small gate openings. Such flows cause cavitation damage just downstream from the gates or gate frames.

The cavitation resistance of many different repair materials has been tested by the laboratories of Reclamation, the U.S. Army Corps of Engineers, and others. To date, no material, including stainless steel and cast iron, has been found capable of withstanding fully developed instances of cavitation. Successful repairs must first include mediation of the causes of cavitation.

A standard rule of thumb is that cavitation damage will not occur at flow velocities less than about 40 feet per second at ambient pressures. As flow velocities approach this threshold, it becomes necessary to ensure that there are no offsets or discontinuities on the surfaces in the flow path. Reclamation's specifications for finishing the surfaces of concrete structures that will experience high velocity flows are very strict. Repairs to newly constructed concrete that fail to meet these

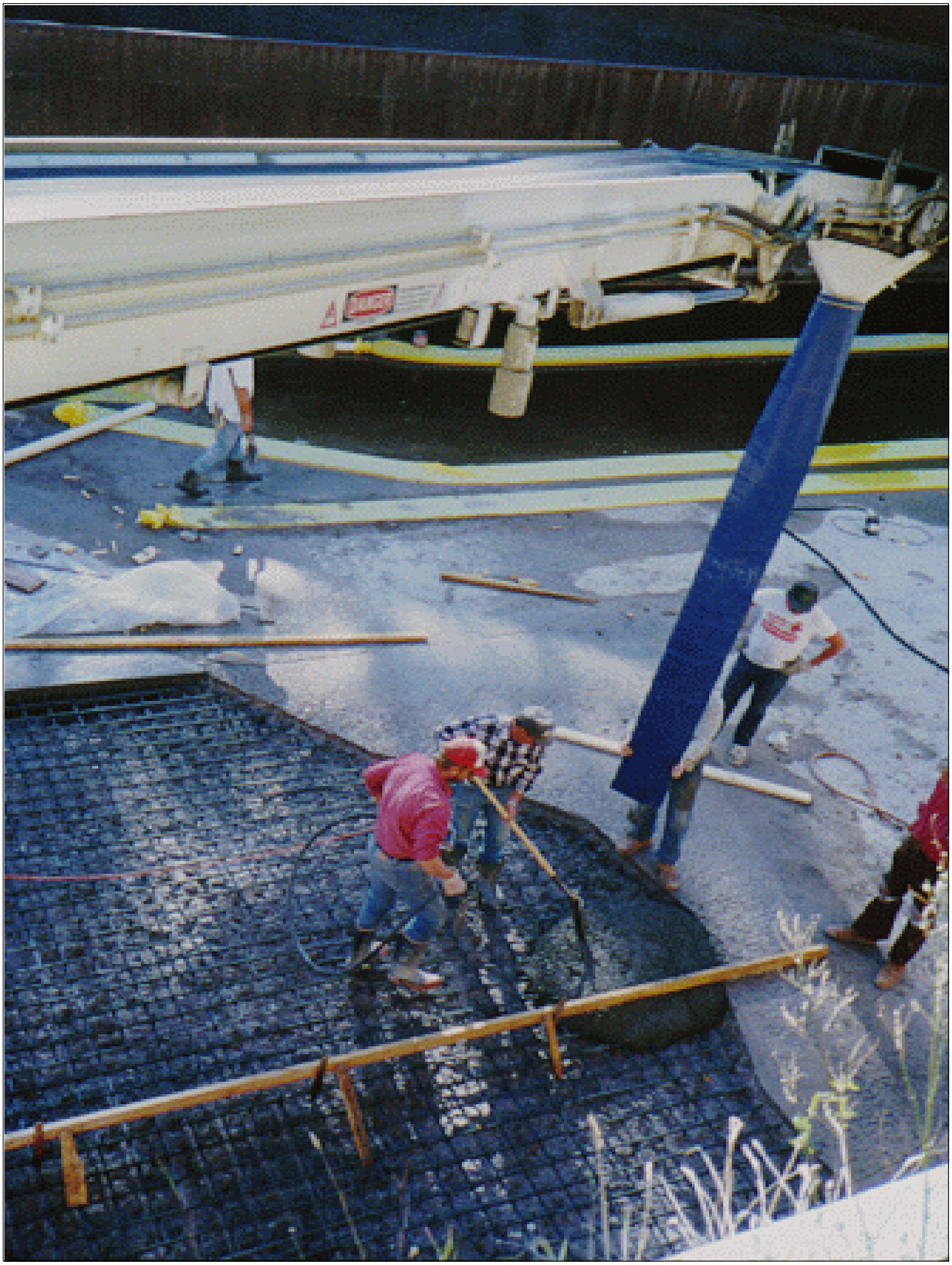

Figure 26.—Placing silica fume concrete to repair a spillway floor damaged by cyclic freezing and thawing and abrasion-erosion.

Figure 27.—Typical Christmas tree pattern of progressive cavitation damage.

Figure 28.—Extensive cavitation damage to Glen Canyon Dam.

requirements can sometimes be accomplished by surface grinding (section 24). More likely, however, the concrete that does not meet surface specifications must be removed and replaced with replacement concrete (section 29) or epoxy-bonded replacement concrete (section 31).

Cavitation damage at, or adjacent to, control gates can usually be repaired with epoxy-bonded epoxy mortar (section 30), polymer concrete (section 32), or epoxy-bonded replacement concrete (section 31). Such damage is usually not very extensive in nature. That is, it is usually discovered before major repairs become necessary. After performing such repairs, it might be a good idea to apply a 100-percent solids epoxy coating to the concrete, beginning at the gate frame and extending downstream 5 to 10 feet. The glass-like surfaces of epoxy coatings may help prevent cavitation damage to the concrete. It should be understood, however, that epoxy coatings will not resist fully developed instances of cavitation damage.

Successful repair of cavitation damage to spillway, outlet works, or stilling basin concrete almost always requires making major modifications to the damaged structure to prevent recurrence of damage. Performance of hydraulic model studies should be considered to ensure correctness of the design of such repair and facility modification. One modification technique, the installation of air slots in spillways and tunnels, has been very successful in eliminating or significantly reducing cavitation damage. Replacement concrete is usually used for construction of such features and the repair of the cavitation damage.

19. Corrosion of Reinforcing Steel.— Corrosion of reinforcing steel is usually a symptom of damage to concrete rather than a cause of damage. That is, some other cause weakens the concrete and allows steel corrosion to occur. However, corroded reinforcing steel is so commonly found in damaged concrete that the purposes of this guide will best be served by discussing it as if it were a cause of damage.

The alkalinity of the portland cement used in concrete normally creates a passive, basic environment (pH of about 12) around the reinforcing steel which protects it from corrosion. When that passivity is lost or destroyed, or when the concrete is cracked or delaminated sufficiently to allow free entrance of water, corrosion can occur. The iron oxides formed during steel corrosion require more space in the concrete than the original reinforcing steel. This creates tensile stresses within the concrete and results in additional cracking and/or delamination which accelerate the corrosion process.

Some of the more common causes of corrosion of reinforcing steel are cracking associated with freeze-thaw deterioration, sulfate exposure, and alkali-aggregate reaction, acid exposure, loss of alkalinity due to carbonation, lack of sufficient depth of concrete cover, and exposure to chlorides.

Exposure to chlorides greatly accelerates the rates of corrosion and can occur in several manners. The application of deicing salts (sodium chloride) to concrete to accelerate thawing of snow and ice is a common source of chlorides. Chlorides can also occur in the sand, aggregate, and mixing water used to prepare concrete mixtures. Some irrigation structures located in the Western States transport waters that have high chloride contents (figure 29). Concrete structures located in marine environments experience chloride exposure from the sea water or from windblown spray. Finally, it was once a somewhat common practice to use concrete admixtures containing chlorides to accelerate the hydration of concrete placed during winter conditions.

The occurrence of corroding reinforcing steel can usually, but not always, be detected by the presence of rust stains on the exterior surfaces and by the hollow or drummy sounds that result from tapping the affected concrete with a hammer. It can also be detected by measuring the half cell potentials of the affected concrete using special electronic devices manufactured specifically for this purpose. When the

Figure 29.—Concrete damage caused by chloride-induced corrosion of reinforcing steel. The waters contained within this flume had high chloride content.

presence of corroding steel has been confirmed, it is important to define what actually caused the corrosion because the cause(s) of corrosion will usually determine which repair procedure should be used. Further discussion of such repair procedures can be found elsewhere in this guide. Once the cause of damage has been defined and mitigated, if necessary, proper preparation of the corroded steel exposed during removal of the deteriorated concrete becomes important. Steel that has been reduced to less than half its original cross section by the corrosion process should be removed and replaced. The remaining steel must then be cleaned to remove all loose rust, scale, and corrosion byproducts that would interfere with the bond to the repair material. Corroded reinforcing steel may extend from areas of obviously deteriorated concrete well into areas of apparently sound concrete. Care must be taken to remove sufficient concrete to include all the corroded steel.

20. Acid Exposure.—The more common sources of acidic exposure involving concrete structures occur in the vicinity of under-ground mines. Drainage waters exiting from such mines can contain acids of sometimes unexpectedly low pH value. A pH value of 7 is defined as neutral. Values higher than 7 are defined as basic, while pH values lower than 7 are acidic. A 15- to 20-percent solution of sulfuric acid will have a pH value of about 1. Such a solution will damage concrete very rapidly. Acidic waters having pH values of 5 to 6 will also damage concrete, but only after long exposure.

Concrete damaged by acids is very easy to detect. The acid reacts with the portland cement mortar matrix of concrete and converts the cement into calcium salts that slough off or are washed away by flowing waters. The coarse aggregate is usually undamaged but left exposed. The appearance of acid-damaged concrete is somewhat like that of abrasion damage, but the exposure of the coarse aggregate is more pronounced and does not appear polished. Figures 30 and 31 show the typical appearance of concrete that has been damaged by acid exposure. Acid damage begins, and is most pronounced, on the exposed

Figure 30.—Concrete deterioration caused by acidic water.

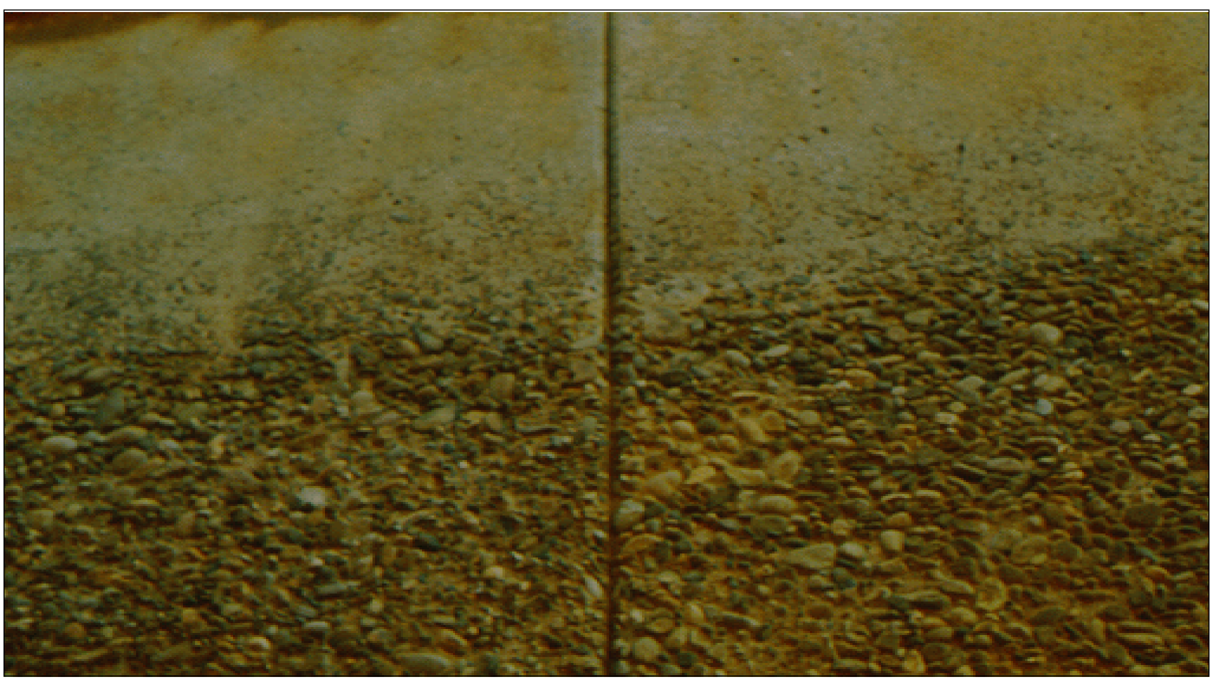

Figure 31.—The depth of acidic water on this concrete wall is very apparent.

surface of concrete but always extends, to a diminishing extent, into the core of the structure. The acid is most concentrated at the surface. As it penetrates into the concrete, it is neutralized by reaction with the portland cement. The cement at depth inside the structure, however, is weakened by the reaction. Preparation of acid-damaged concrete, therefore, always involves removal of more concrete than would otherwise be expected. Failure to remove all the concrete affected and weakened by the acid will result in bond failure of the repair material. Acid washes were once permitted as a method of cleaning concrete surfaces in preparation for repairs. It has been learned, however, that bond failures would occur unless extensive efforts were expended to remove all traces of acid from the concrete. Reclamation specifications no longer permit the use of acid washes to prepare concrete for repair or to clean cracks subject to resin injection repairs.

As with all causes of damage to concrete, it is generally necessary to remove the source of damage prior to repair. The most common technique used with acid damage is to dilute the acid with water. Low pH acid solutions can be converted to higher pH solutions having far less potential for damage in this manner. Alternately, if the pH of the acid solution is relatively high, coatings such as the thin polymer concrete coating system, section 33, can be applied over repair materials to prevent the acid from redamaging the surfaces. Laboratory tests have revealed very few economical coatings capable of protecting repair materials from low pH solutions.

Repairs to acid-damaged concrete can be made using epoxy-bonded replacement concrete (section 31), replacement concrete (section 29), polymer concrete (section 32), and, in some instances, epoxy-bonded epoxy mortar (section 30). Polymer concrete and epoxy mortar, which do not contain portland cement, offer the most resistance to acid exposure conditions.

21. Cracking.—Cracking, like corrosion of reinforcing steel, is not commonly a cause of damage to concrete. Instead, cracking is a symptom of damage created by some other cause.

All portland cement concrete undergoes some degree of shrinkage during hydration. This shrinkage produces multidirectional drying shrinkage and curing shrinkage cracking having a somewhat circular pattern (figure 32). Such cracks seldom extend very deeply into the concrete and can generally be ignored.

Plastic shrinkage cracking occurs when the fresh concrete is exposed to high rates of evaporative water loss which causes shrinkage while the concrete is still plastic (figure 33). Plastic shrinkage cracks are usually somewhat deeper than drying or curing shrinkage cracks and may exhibit a parallel orientation that is visually unattractive.

Thermal cracking is caused by the normal expansion and contraction of concrete during changes of ambient temperature. Concrete has a linear coefficient of thermal expansion of about 5.5 millionths inch per inch per degree Fahrenheit (°F). This can cause concrete to undergo length changes of about 0.5 inch per 100 linear feet for an 80 °F temperature change. If sufficient joints are not provided by the design of the structure to accommodate this length change, the concrete will simply crack and provide the joints where needed. This type of cracking will normally extend entirely through the member and create a source of leakage in water retaining structures. Thermal cracking can also be caused by using portland cements developing high heats of hydration during curing. Such concrete develops exothermic heat and hardens while at elevated temperatures. Subsequent contraction upon cooling develops internal tensile stresses and resulting cracks at or across points of restraint.

Inadequate foundation support is another common cause of cracking in concrete structures. The tensile strength of concrete is usually only about 200 to 300 psi. Foundation settlement can easily create displacement conditions where the tensile strength of concrete

Figure 32.—Typical appearance of drying shrinkage cracking.

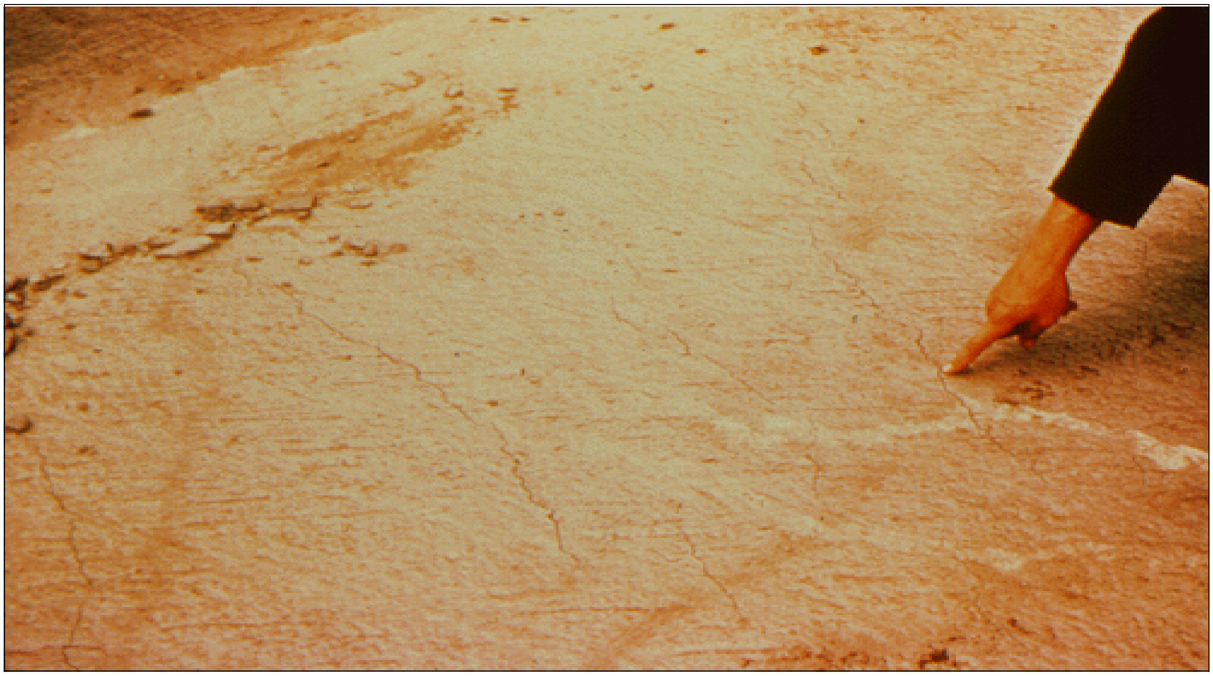

Figure 33.—Plastic shrinkage cracking caused by high evaporative water loss while the concrete was still in a plastic state.

is exceeded with resulting cracking.

Cracking is also caused by alkali-aggregate reaction, sulfate exposure, and exposure to cyclic freeze-thaw conditions, as has been discussed in previous sections, and by structural overloads as discussed in the following section.

Successful repair of cracking is often very difficult to attain. It is better to leave most types of concrete cracking unrepaired than to attempt inadequate or improper repairs (figure 34 and 35). The selection of methods for repairing cracked concrete depends on the cause of the cracking. First, it is necessary to determine if the cracks are "live" or "dead." If the cracks are cyclicly opening and closing, or progressively widening, structural repair becomes very complicated and is often futile. Such cracking will simply reestablish in the repair material or adjacent concrete. For this reason, it is normal procedure to install crack gages across the cracks to monitor their movement prior to attempting repair (figure 36). The gages should be monitored for extended periods to determine if the cracks are simply opening and closing as a result of daily or seasonal temperature changes or if there is a continued or progressive widening of the cracks resulting from foundation or

load conditions. Repairs should be attempted only after the cause and behavior of the cracking is understood.

If it is determined that the cracks are "dead" or static, epoxy resin injection (section 34) can be used to structurally rebond the concrete. If the objective of the repair is to seal water leakage rather than to accomplish structural rebonding, the cracks should be injected with polyurethane resin. Epoxy resin injection can sometimes be used to seal low volume water leakage and structurally rebond cracked concrete members. Epoxy resins cure to form hard, brittle materials that will not withstand movement of the injected cracks. Poly-urethane resins cure to a flexible, low tensile strength, closed cell foam that is effective in sealing water leakage but cannot normally be used for structural rebonding. (Some two component polyurethane resin systems cure to form flexible solids that may be

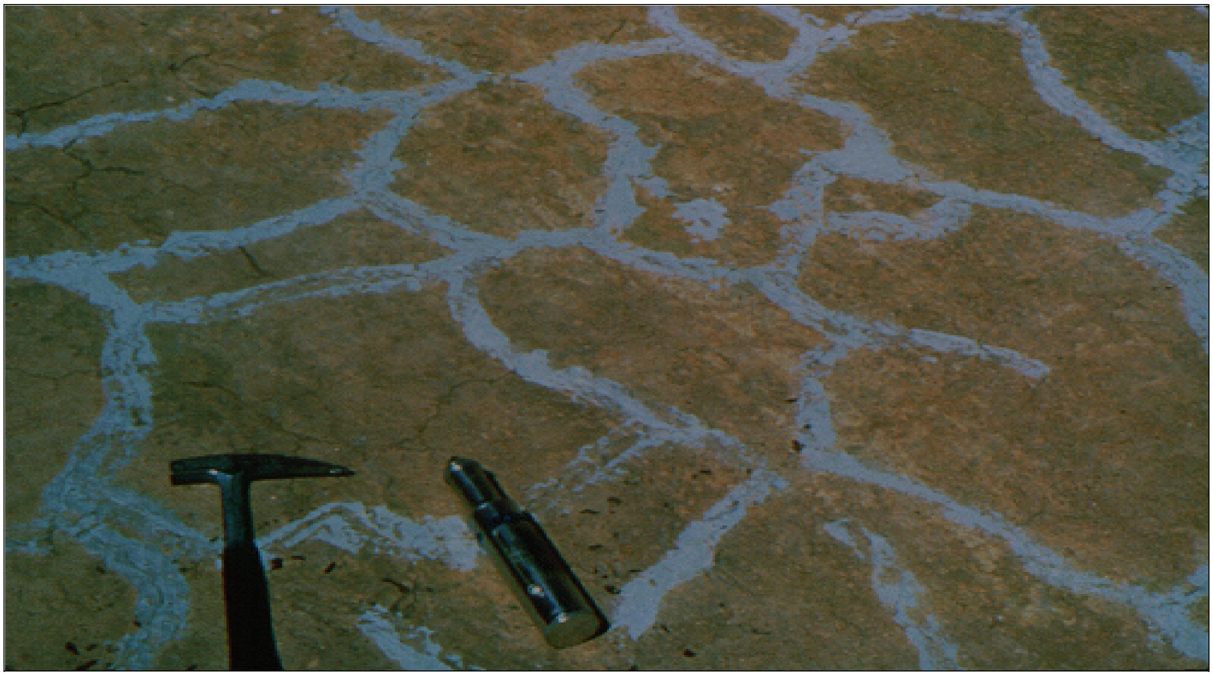

Figure 34.—Inadequate crack repair techniques often result in poor appearance upon completion.

Figure 35.—Improper crack repair techniques often result in short service life.

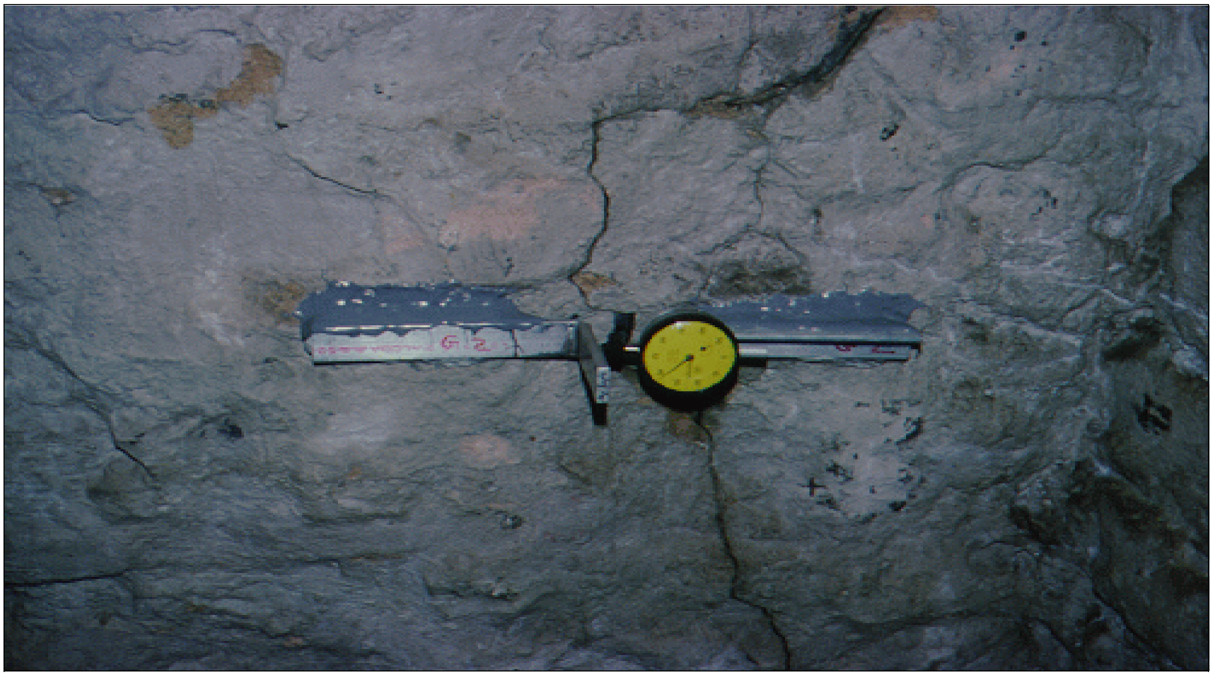
Figure 36.—Crack gage installed across a crack will allow determination of progressive widening or movement of the crack. It may be necessary to monitor such gages for periods up to a year to predict future crack behavior.

useful for structural rebonding.) These flexible foams can experience 300- to 400-percent elongation due to crack movement. It is not uncommon to find that damaged concrete contains cracking not related to the cause of the primary damage (see section 23). If the depth of removal of the damaged or deteriorated concrete does not extend below the depth and extent of the existing cracks, it should be expected that the cracking will ultimately reflect through the new repair materials. Such reflective cracking is common in bonded overlay repairs to bridge decks, spillways, and canal linings (figure 37). If reflective cracking is intolerable, the repairs must be designed as separate structural members not bonded to the old existing concrete.

22. Structural Overloads.—Concrete damage caused by structural overloading is usually very obvious and easy to detect. Frequently, the event causing overloading has been noted and is a matter of record. The stresses created by overloads result in distinctive patterns of cracking that indicate the source and cause of excessive loading and the point(s) of load application. Normally, structural overloads are one time events and, once defined, the resulting damage can be repaired with the expectation that the cause of the damage will not reoccur to create damage in the repaired concrete.

It should be expected that the assistance of a knowledgeable structural engineer will be required to perform the structural analysis needed to fully define and evaluate the cause and resulting damage of most structural overloads and to assist in determining the extent of repair required. This analysis should include determination of the loads the structure was designed to carry and the extent the overload exceeded design capacity. A thorough inspection of the damaged concrete must be performed to determine the entire effect of the overload on the structure. Displacements must be discovered and the secondary damage, if any, located. Care should be taken to ensure that some other cause of damage did not first

Figure 37.—A large reflective crack has formed in a concrete overlay which also exhibits circular drying shrinkage cracking.

weaken the concrete and make it incapable of carrying the design loads. The repair of damage caused by overloading can, most likely, best be performed with conventional replacement concrete (section 29). The need for repair and/or replacement of damaged reinforcing steel should be anticipated and included in the repair procedures.

23. Multiple Causes of Damage.—Multiple causes of the damage should be suspected whenever damage or deterioration is discovered in modern concrete. Modern concrete (concrete constructed since about 1950) has the benefit of the use of various admixtures and advanced concrete materials technology. Such concrete should not be damaged by many of the causes listed in this chapter. If deterioration or damage has occurred, it is likely that a combination of causes are in effect. Failure to recognize and mitigate all the causes of damage will most likely result in poor repair serviceability. Figure 38 shows the results of multiple cause damage. This concrete is suffering from alkali-aggregate reaction cracking that has also accelerated freeze-thaw deterioration of the surface. It is also being damaged by faulty design or construction techniques that located the electrical conduits too close to the exterior surface of the concrete.

The proper use of air entraining admixtures in modern concrete has greatly increased the resistance of the concrete to freeze-thaw deterioration. Except in unusually severe exposures, freeze-thaw deterioration should not occur. This notwithstanding, freeze-thaw deterioration is often still blamed as the cause of damage to modern concrete. Before blaming freezing and thawing conditions, it is better to first determine why the air entraining admixture did not provide effective protection. Mix records and aggregate quality test results may indicate that the concrete was poorly proportioned or that the available aggregate was of low quality. Construction inspection records may indicate that placing and finishing techniques were inadequate. Petrographic examination of the affected concrete may reveal that alkali-aggregate reaction, sulfate exposure, or induced chlorides have weakened the concrete and allowed freeze-thaw damage to occur. All such findings might indicate that the problem is far more extensive than at first thought and requires more extensive preventative or corrective action than the simple replacement of the presently deteriorated concrete.

The use of excessive mix water, the improper type of portland cement, poor construction practices, improper mixture proportioning, dirty or low quality aggregate, and inadequate curing all contribute to low durability in concrete. Such concrete may have low resistance to normal weathering or to other hazards.

Selection of the proper methods and materials for repair of concrete damaged by multiple causes depends on determining which is the weakening cause and which is the accelerated cause. Once the weakening cause is fully understood, it is commonly necessary to take preventative measures to protect the re-maining original concrete from additional damage. The application of concrete sealing compounds (sections 35 and 38) or the thin polymer concrete overlay (section 32) may prove useful in this respect. If no such preventative measures are judged useable, repair of the damaged concrete can be made as discussed in previous sections, but short repair service life and the occurrence of future damage should be anticipated.

Figure 38.—Multiple causes of damage are apparent in this photograph. Poor design or construction practices placed the electrical conduit too near the surface. A combination of freezing and thawing deterioration and alkali-aggregate reaction is responsible for the cracking and surface spalling on the parapet wall.

Chapter IV

Standard Methods of Concrete Repair

Proven methods of repairing concrete are described in this chapter. Sections 24 through 38 contain detailed discussions of each of the proven repair methods. Construction specifications for these methods/materials of repair are contained in the latest revision of Reclamation's *Standard Specifications for the Repair of Concrete, M-47,* Appendix A. It is essential that the provisions of these specifications be closely followed during repair of Reclamation concrete. It should be recognized, however, that these "standard" methods and specifications cannot apply to unusual or nonstandard concrete repair situations. Assistance with unusual or special repair problems can readily be obtained by contacting personnel of the Materials Engineering and Research Laboratories, Code D-8180.

24. Surface Grinding.—Surface grinding can be used to repair some bulges, offsets, and other irregularities that exceed the desired surface tolerances. Excessive surface grinding, however, may result in weakening of the concrete surface, exposure of easily removed aggregate particles, or unsightly appearance. For these reasons, surface grinding should be performed subject to the following limitations:

a. Grinding of surfaces subject to cavitation erosion (hydraulic surfaces subject to flow velocities exceeding 40 feet per second) should be limited in depth so that no aggregate particles more than 1/16 inch in cross section are exposed at the finished surface.

b. Grinding of surfaces exposed to public view should be limited in depth so that no aggregate particles more than 1/4 inch in cross section are exposed at the finished surface.

c. In no event should surface grinding result in exposure of aggregate of more than one-half the diameter of the maximum size aggregate.

Where surface grinding has caused or will cause exposure of aggregate particles greater than the limits of subparagraph 24.a. or b., the concrete must then be repaired by excavating and replacing the concrete in accordance with sections 29, 30, 31, or 32.

25. Portland Cement Mortar.—Portland cement mortar may be used for repairing defects on surfaces not prominently exposed, where the defects are too wide for dry pack filling or where the defects are too shallow for concrete filling and no deeper than the far side of the reinforcement that is nearest the surface. Repairs may be made either by use of shotcrete or by hand application methods. Replacement mortar can be used to make shallow, small size repairs to new or green concrete, provided that *the repairs are performed within 24 hours of removing the concrete forms.*

The use of replacement mortar to repair old or deteriorated concrete has been permitted on Reclamation projects in the past. It is now recognized, however, that accomplishing successful mortar repairs to old concrete without the use of a bonding resin is unlikely or extremely difficult. Evaporative loss of water from the surface of the repair mortar, combined with capillary water loss to the old concrete, results in unhydrated or poorly hydrated cement in the mortar. Additionally, repair mortar bond strength development proceeds at a slower rate than compressive strength development. This causes workers to mistakenly abandon curing procedures prematurely, when the mortar "seems strong." Once the mortar dries, bond strength development stops, and bond failure of the mortar patch results.

For these reasons, using cement mortar without a resin bond coat to repair old concrete is discouraged and is not allowed under Reclamation's *Standard Specifications for the Repair of Concrete, M-47*.

A portland cement mortar patch is usually darker than the surrounding concrete unless precautions are taken to match colors (figure 39). A leaner mix will usually produce a lighter color patch. Also, white cement can be used to produce a patch that will blend with the surrounding concrete. The quantity of white cement to use must be determined by trial.

(a) Preparation.—Concrete to be repaired with replacement mortar should be prepared in accordance with the provisions of section 8. After preparation, the areas should be cleaned, roughened, if necessary (preferably by wet sandblasting), and surface dried to a saturated surface condition. The mortar should be applied immediately thereafter.

(b) Materials.—Replacement mortar contains water, portland cement, and sand. The cement should be same type as used in the concrete being repaired. The water and sand should be suitable for use in concrete, and the sand should pass a No. 16 sieve. The cement to sand ratio should be between 1:2 to 1:4, depending on application technique. Only enough water should be added to the cement-sand mixture to permit placing.

(c) Application.—Best results with replacement mortar are obtained when the material is pneumatically applied using a small gun. Equipment commonly used for shotcreting is too large to be satisfactory for the ordinarily small size mortar repairs of new concrete. With shotcreting equipment, neat work is difficult in the usual small areas, and cleanup costs are high because cleanup is seldom done promptly. However, small size equipment such as shown in figure 40 has been satisfactory for small scale repair work when the mortar was premixed, including water, to a consistency of dry-pack material. No initial application of cement, cement grout, or wet mortar should be made. If repairs are more than 1 inch deep, the mortar should be applied in layers not more than 3/4 of an inch thick to avoid sagging and loss of bond. After completion of each layer, there should be a lapse of 30 minutes or more before the next layer is placed. Scratching or otherwise preparing the surface of a layer prior to addition of the next layer is unnecessary, but the mortar must not be allowed to dry.

In completing the repair, the hole should be filled slightly more than level full. After the material has partially hardened but can still be trimmed off with the edge of a steel trowel, excess material should be shaved off, working from the center toward the edges. Extreme care must be used to avoid impairment of bond. Neither the trowel nor water should be used in finishing. A satisfactory finish may be obtained by lightly rubbing the surface with a soft rag.

For minor restorations, satisfactory mortar replacement may be performed by hand. The success of this method depends on complete removal of all defective and affected concrete, good bonding of the mortar to the concrete, elimination of shrinkage of the patch after placement, and thorough curing.

Replacement mortar repairs can be made using an epoxy bonding agent as described in section 26. This technique, while not required by Reclamation's M-47 specifications, is highly recommended.

(d) Curing.—Failure to cure properly is the most common cause of failure of replacement mortar. It is essential that mortar repairs receive a thorough water cure starting immediately after initial set and continuing for 14 days. In no event should the mortar be allowed to become dry during the 14-day period following placement. Following the 14-day water cure and while the mortar is still saturated, the surface of the mortar should

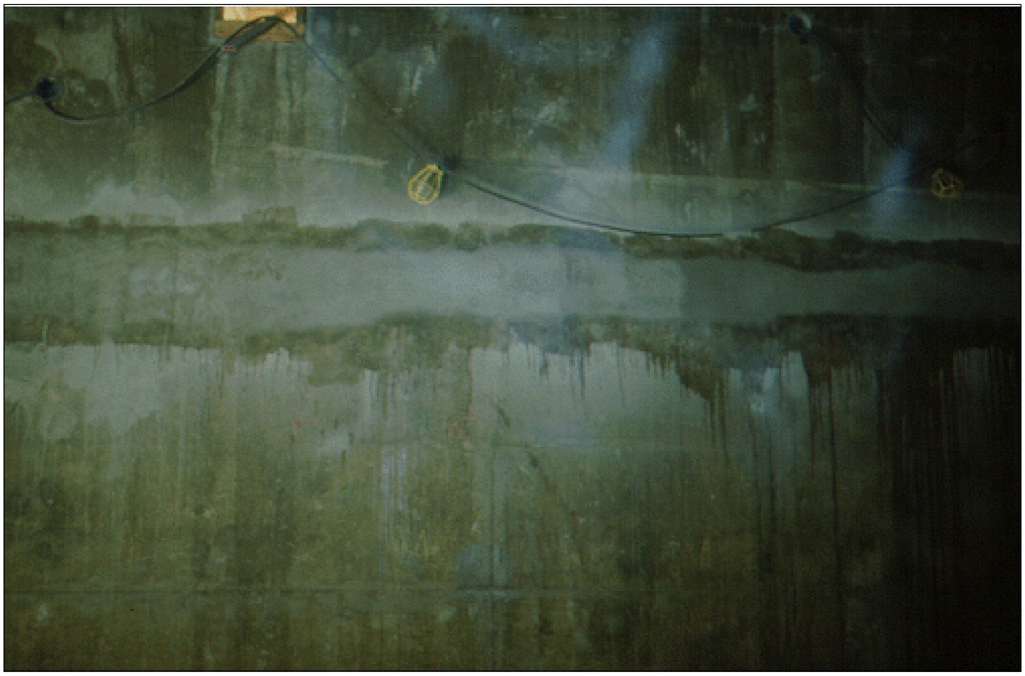

Figure 39.—A portland cement mortar patch seldom matches the color of the original concrete unless special efforts are taken to blend white cement with normal portland cement.

Figure 40.—A small size pneumatic gun can be used to apply portland cement mortar. Regular shotcreting equipment would be too large for this application.

be coated with two coats of a wax-base or water-emulsified resin base curing compound meeting Reclamation specifications. If this curing procedure cannot be followed or if conditions at the job are such that this curing procedure will not be followed, money would be saved by using another repair material.

26. Dry Pack and Epoxy-Bonded Dry Pack.—Dry pack is a combination of portland cement and sand passing a No. 16 sieve mixed with just enough water to hydrate the cement. Dry pack should be used for filling holes having a depth equal to, or greater than, the least surface dimension of the repair area; for cone bolt, she bolt, core holes, and grout-insert holes; for holes left by the removal of form ties; and for narrow slots cut for repair of cracks. Dry pack should not be used for relatively shallow depressions where lateral restraint cannot be obtained, for filling behind reinforcement, or for filling holes that extend completely through a concrete section.

For the dry pack method of concrete repair, holes should be sharp and square at the surface edges, but corners within the holes should be rounded, especially when water tightness is required. The interior surfaces of holes left by cone bolts and she bolts should be roughened to develop an effective bond; this can be done with a rough stub of 7/8-inch steel-wire rope, a notched tapered reamer, or a star drill. Other holes should be undercut slightly in several places around the perimeter, as shown in figure 41. Holes for dry pack should have a minimum depth of 1 inch.

(a) Preparation.—Application of dry pack mortar should be preceded by a careful inspection to see that the hole is thoroughly cleaned and free from mechanically held loose pieces of aggregate. One of the three following methods should be used to ensure good bond of the dry pack repair.

The first method is the application of a stiff mortar or grout bond coat immediately before applying the dry pack mortar. The mix for the bonding grout is 1:1 cement and fine sand mixed with water to a fluid paste consistency. All surfaces of the hole are thoroughly brushed with the grout, and dry packing is done quickly before the bonding grout can dry. Under no circumstances should the bonding coat be so wet or applied so heavily that the dry pack material becomes more than slightly rubbery. When a grout bond coat is used, the hole to be repaired can be dry. Presoaking the hole overnight with wet rags or burlap prior to dry packing may sometimes give better results by reducing the loss of hydration water, but there must be no free surface water in the hole when the bonding grout is applied.

The second method of ensuring good bond starts with presoaking the hole overnight with wet rags or burlap. The hole is left slightly wet with a small amount of free water on the inside surfaces. The surfaces are then dusted lightly and slowly with cement using a small dry brush until all surfaces have been covered and the free water absorbed. Any dry cement in the hole should be removed using a jet of air before packing begins. The hole should not be painted with neat cement grout because it could make the dry pack material too wet and because high shrinkage would prevent development of the bond that is essential to a good repair.

A third method of ensuring good bond is the use of an epoxy bonding resin. The epoxy bonding resin should meet the requirements of ASTM C-881 for a type II, grade 2, class B or C resin, depending on the job site ambient temperatures. Epoxies bond best to dry concrete. It may be necessary to dry the hole immediately prior to dry packing using hot air, a propane torch, or other appropriate method. The concrete temperature, however, should not be high enough to cause instant setting of the epoxy or to burn the epoxy when it is applied. After being mixed, the epoxy is thoroughly brushed to cover all surfaces, but any excess epoxy is removed. Dry pack mortar is then applied immediately, before the epoxy starts to harden. The epoxy must be either fluid or tacky when dry packing takes place. If it appears that the epoxy may become hard before dry packing is

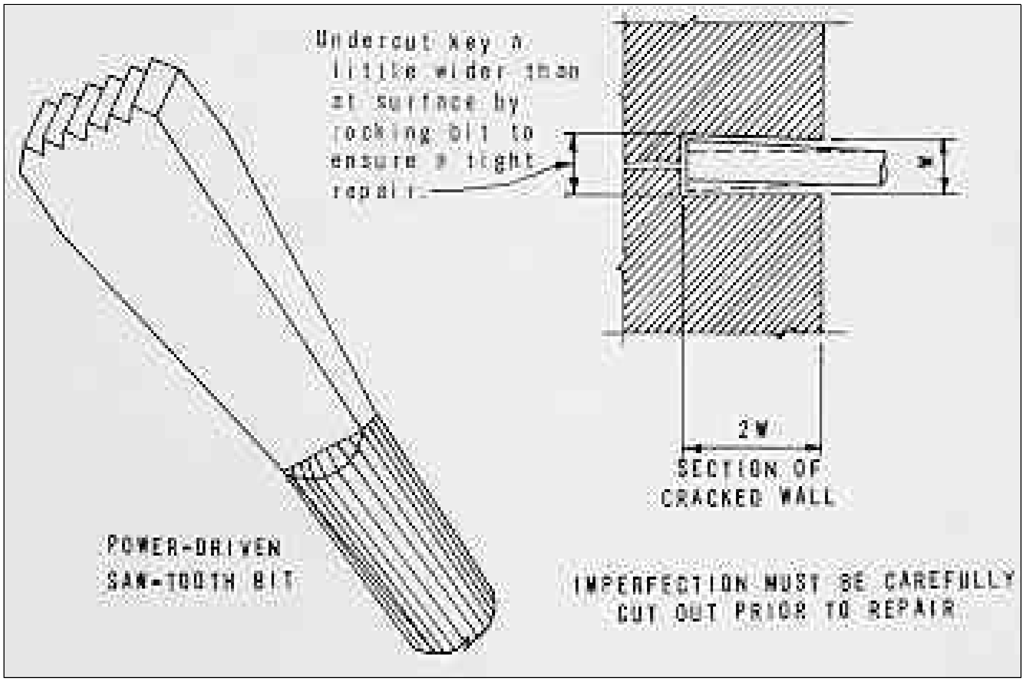

Figure 41.—Saw-tooth bit used to cut slot for dry packing.

complete, fresh fluid epoxy can be brushed over epoxy that has become tacky. If the epoxy becomes hard, it must be removed before a new coat is applied. The epoxy ensures a good bond between the dry pack repair and the old concrete. It also reduces the loss of hydration water from the repair to the surrounding concrete, thus assisting in good curing; however, the epoxy-bonded dry pack still requires curing as discussed below. Where appearance is not important, epoxy has sometimes been used on the surface in place of a curing compound. This procedure is not recommended and is not allowed on Reclamation jobs.

(b) Materials.—Dry pack mortar is usually a mixture (by dry volume or weight) of 1 part cement to 2-1/2 parts sand that will pass a No. 16 screen. While the mixture is rich in cement, the low water content prevents excessive shrinkage and gives high strengths. A dry pack repair is usually darker than the surrounding concrete unless special precautions are taken to match the colors. Where uniform color is important, white cement may be used in sufficient amount (as determined by trial) to produce uniform appearance. For packing cone bolt holes, a leaner mix of 1:3 or 1:3-1/2 will be sufficiently strong and will blend better with the color of the wall. Sufficient water should be used to produce a mortar that will just stick together while being molded into a ball with the hands and will not exude water but will leave the hands damp. The proper amount of water will produce a mix at the point of becoming rubbery when solidly packed. Any less water will not make a sound, solid pack; any more will result in excessive shrinkage and a loose repair.

(c) Application.—Dry pack mortar should be placed and packed in layers having a compacted thickness of about three-eighths of an inch. Thicker layers will not be well compacted at the bottom. The surface of each layer should be scratched to facilitate bonding with the next layer. One layer may be placed immediately after another unless an appreciable rubbery quality develops; if this occurs, work on the repair should be delayed 30 to 40 minutes. Under no circumstances should alternate layers of wet and dry materials be used.

Each layer should be solidly compacted over the entire surface by striking a hardwood dowel or stick with a hammer. These sticks are usually 8 to 12 inches long and not over 1 inch in diameter and are used on fresh mortar like a caulking tool. Hardwood sticks are used in preference to metal bars because the latter tend to polish the surface of each layer and, thus, make bonding less certain and filling less uniform. Much of the tamping should be directed at a slight angle and toward the sides of the hole to ensure maximum compaction in these areas. The holes should not be overfilled; finishing may usually be completed at once by laying the flat side of a hardwood piece against the fill and striking it several good blows with a hammer. If necessary later, a few light strokes with a rag may improve appearance. Steel finishing tools should not be used, and water must not be used to facilitate finishing.

(d) Curing and Protection.—Procedures for curing and protection of dry pack are essentially the same as those for concrete and are described in section 25. Additionally, the dry pack repair area should be protected and not exposed to freezing temperatures for at least 3 days after application of the curing compound.

27. Preplaced Aggregate Concrete.— Preplaced aggregate concrete is an excellent repair material that has not been used much in recent years. Preplaced aggregate concrete is made by injecting portland cement grout, with or without sand, into the voids of a formed, compacted mass of clean, graded, coarse aggregate. The preplaced aggregated is washed and screened to remove fines before placing into the forms. As the grout is injected or pumped into the forms, it displaces any included air or water and fills the voids around the aggregate, thus creating a dense concrete having a high aggregate content.

Because the coarse aggregate has point contact prior to grout injection, preplaced aggregate concrete undergoes very little settlement, curing, or drying shrinkage during hydration. Drying shrinkage of preplaced aggregate concrete containing 1-1/2 inch maximum size aggregate is about 200 to 400 millionths, while conventional concrete drying shrinkage containing the same size maximum aggregate is about 400 to 600 millionths.

Another advantage of preplaced aggregate concrete is the ease with which it can be placed in certain situations where placement of conventional concrete would be extremely difficult or impossible. Preplaced aggregate concrete is especially useful in underwater repair construction. It has been used in a variety of large concrete and masonry repairs, including bridge piers and the resurfacing of dams. It has been used to construct atomic reactor shielding and plugs for outlet works and tunnels in mine workings, and it has been used to embed penstocks and turbine scrollcases (American Concrete Institute, 1992). Figure 42 shows the upstream face of Barker Dam near Boulder, Colorado, which was resurfaced with prepacked aggregate concrete.

Although preplaced aggregated is adaptable to many special repair applications, it is essential that the work be undertaken by well qualified personnel who are willing to follow exactly the construction procedures required for this repair material. Form work for preplaced aggregate concrete requires special attention to prevent grout loss. The construction of forms should be with workmanship better than that normally encountered with conventional concrete. Leaking forms can cause significant problems and should, by careful construction, be avoided whenever possible. The injected grout is more flowable than plastic concrete and takes slightly longer to set. Forms, therefore, must be constructed to take more lateral pressure than would be necessary with conventional concrete. Form bolts should fit tightly through the sheathing, and all possible points of grout leakage should be caulked.

(a) Preparation The preparation of concrete to be repaired by preplaced aggregate concrete is identical to the preparation required for replacement concrete (section 29) if the development of bond is required.

Figure 42.—The downstream face of Barker Dam, near Boulder, Colorado, was resurfaced with prepacked aggregate.

(b) Materials .—Grout for preplaced aggregate concrete may be mixed with sand either of the gradation specified for conventional concrete or with fine sand, pozzolanic or fly ash fillers, water reducing admixtures, and pumping admixtures as dictated by the minimum size of the coarse aggregate. With 1-1/2-inch minimum size coarse aggregate, the sand gradation is that specified for conventional concrete. The portland cement, water, and sand are mixed using high speed centrifugal grout mixers that produce well mixed grouts of a creamy consistency. For use with 1/2-inch minimum size coarse aggregate, a grout mixture is prepared containing fine sand passing a No. 8 screen and with at least 95 percent passing a No. 16 screen. Best pumping characteristics will be obtained with fineness modulus between 1.2 and 2 and with the rounded shape of natural sands as opposed to crushed sands.

Addition of fly ash and water reducing admixture improves the flowability of the grout and the ultimate strength. Proprietary pumping admixtures are commonly used to increase the penetration and pumpability of the final grout. The consistency of grout for preplaced aggregated should be uniform from batch to batch and should be such that it can be readily pumped into the voids at relatively low pressure. Consistency is affected by water content, sand grading, filler type and content, cement type, and admixture type. For each mix, there are optimum proportions that produce best grout pumpability or consistency, and tests are necessary for each job to determine these optimum proportions.

The maximum size coarse aggregate used with both types of grout is the largest available, provided that the aggregate can be easily handled and placed. Coarse aggregate should meet all the requirements of coarse aggregate for conventional concrete. It is essential that the coarse aggregated be clean. The aggregate should be well graded from minimum size (1/2-inch minimum or 1-1/2-inch minimum) up to the maximum size, and when compacted into the forms, should have a void content of 35 to 40 percent. If grout containing sand of concrete grading is used, the minimum coarse aggregate size should be 1-1/2 inches.

(c) Application.—The grout piping system used with preplaced aggregate concrete must be designed to serve at least 3 purposes—to deliver and inject grout, to provide means for determining grout level in the forms, and to serve as vents in enclosed forms for escape or air and water. Proper design and location of the grout piping system is essential for successful placement.

The grout delivery pipeline should be a recirculating system. That is, the grout delivery pipeline should extend from the grout agitator or holding tank to the grout pump, then to the injection manifold, and return to the grout agitator tank. With this type of pipeline, the grout can be kept moving and circulating in the delivery pipeline even when no grout is being injected into the aggregate. Such a system prevents stoppages and clogging of the delivery line. Noncirculating or deadheaded grout delivery lines are not allowed on Reclamation projects. The delivery line should be kept as short as practicable, and the pipe size should be such that normal grout flow velocities range between 2 and 4 feet per second. For most applications, a 1-inch ID grout line will suffice. All valves used in the grout piping system should be quick opening ball valves which can be readily cleaned.

The simplest piping system is a single recirculating delivery line attached via a manifold and valves to a single injection line. The injection line should extend to the lowest point in the form. Multiple injection lines are used for larger projects. Spacing of the injection lines is variable, depending on the form configuration, aggregate gradation, and other factors, but spacings of 4 to 6 feet are common. In preparing the layout of the grout delivery system, it is normally assumed that the slope of the grout face will be 4:1 for work in the dry and 6:1 for underwater work. Much flatter slopes are common with actual grout surfaces.

Sounding wells constructed from 2-inch-diameter slotted pipe are installed to allow determination of the level of grout during injection. Similarly, clear plastic windows can be installed in the forms to allow visual determination of grout levels. The number and location of sounding wells are determined by the size and configuration of the aggregate mass. The ratio of sounding wells to injection pipes should be from 1:4 to about 1:8.

Grout injection should begin at the lowest point of the form and continue uniformly until the entire form is filled. After sufficient grout has been pumped to raise the level of grout in the form about 18 inches above the bottom outlet of the injection line, the injection line can be progressively raised, maintaining about 12 inches of embedment below the level of the grout at all times. A great deal of thought and planning is required if multiple injection lines are used. The objective is to entirely fill the form without trapping air or water. Vents must be located where needed and the injection sequence designed to promote complete filling. It is not possible to use internal vibrators to consolidate preplaced aggregate concrete. External vibrators, however, can be attached to the forms and used advantageously. External vibration will eliminate the splotchy appearance that can occur where coarse aggregate particles contact the forms. Underwater applications of preplaced aggregate concrete require additional considerations. During injection, grout pumping must continue until an undiluted flow of grout emerges from the top of the form. Formwork is usually closed at the top to prevent washout or dilution of the grout after placement if flowing water is encountered. Anti-washout admixtures might prove useful for underwater applications of preplaced aggregate concrete. Care must be taken, however, when using several different types of admixtures (e.g., anti-washout, pumping aids, or high range water reducers) that undesirable combinations are avoided. It is known for example, that some anti-washout admixtures can significantly reduce the pumpability benefits of some high range water reducers. Such problems should be detected during the mixture proportioning tests previously recommended in paragraph (b).

The minimum volume of the grout mixer tank and the grout agitator tank should be 17 cubic feet. The grout should be mixed using a high speed centrifugal mixer operating at a minimum of 1,500 rotations per minute. The grout pump should be of the helical screw, rotor-type (commonly known as a "Moyno" grout pump), capable of pumping at least 20 gallons of grout per minute at the specified injection pressure.

Quality control of preplaced aggregate concrete lies with proper compaction of the aggregate into the forms and maintenance of proper grout consistency throughout the job. Compaction requirements must be satisfied by visual inspection during placement and before grout is introduced into the forms. Grout consistency can be determined by using a Baroid Model 140 Mud Balance to measure grout density. Some practitioners promote using a flow cone to time the rate of flow of a known volume of grout through the cone as a measure of consistency. Recent laboratory tests (Smoak, 1993), however, have proven that the flow cone is useless for measuring the consistency of grout containing high range water reducing admixture.

(d) Curing.—The curing requirements for preplaced aggregate concrete are the same as for replacement concrete (section 29). Preplaced aggregate concrete placed during underwater applications will normally receive excellent curing without further effort.

28. Shotcrete.—Shotcrete is defined as "mortar or concrete pneumatically projected at high speed onto a surface" (American Concrete Institute, 1990). There are two basic types of shotcrete—dry mix and wet mix. In dry mix shotcrete, the dry cement, sand, and coarse aggregate, if used, are premixed with only sufficient water to reduce dusting. This mixture is then forced through the delivery line to the nozzle by compressed air (figure 43). At the nozzle, sufficient water is added to the moving stream to meet the requirements of cement hydration. Figure 44 shows the nozzle and water ring of a dry mix shotcrete nozzle. For wet mix shotcrete, the cement, sand, and coarse aggregate are first conventionally mixed with water (figure 45), and the resulting concrete is then pumped to the nozzle where compressed air propels the wet mixture onto the desired surface (figure 46). The two types of shotcrete produce mixes with different water contents and different application characteristics as a result of the distinctly different mixing processes. Dry mix shotcrete suffers high dust generation and rebound losses varying from about 15 percent to up to 50 percent. Wet mix shotcrete must contain enough water to permit pumping through the delivery line. Wet mix shotcrete, as a result, may experience significantly more cracking problems due to the excess water and drying shrinkage. Advances in the development of the high range water reducing admixtures, pumping aids, and concrete pumping equipment since about 1960 have greatly reduced these problems, and wet mix shotcrete is now being used more frequently in repair construction.

Shotcrete is a very versatile construction material that can be readily placed and successfully used for a variety of concrete repair applications. The necessity of form work can be eliminated in many repair applications by use of shotcrete. Shotcrete has been used to repair canal and spillway linings and walls, the faces of dams, tunnel linings, highway bridges and tunnels, deteriorating natural rock walls and earthen slopes, and to thicken and strengthen existing concrete structures. Provided the proper materials, equipment, and procedures are employed, such shotcrete repairs can be accomplished quickly and economically. This apparent ease of application should not cause one to believe that shotcrete repair is a simple procedure or one that can be haphazardly or improperly applied

Figure 43.—Dry mix shotcrete equipment being used in the Denver concrete laboratories.

Figure 44.—Dry mix shotcrete equipment showing the nozzle and water injection ring.

Figure 45.—Wet mix shotcrete equipment. The premixed shotcrete is delivered to the shotcrete pump by a transit truck.

Figure 46.—Wet mix shotcrete is propelled by compressed air.

with impunity. The following two paragraphs contain a very descriptive warning of such practices:

> "Regardless of the considerable ad-vantages of the shotcrete process and its ability to provide finished work of the highest quality, a large amount of poor and sometimes unacceptable work has unfortunately occurred in the past, with the result that many design and construction professionals are hesitant to employ the process. As with all construction methods, failure to employ proper procedures will result in inferior work. In the case of shotcrete the deficiencies can be severe, requiring complete removal and replacement.
>
> "Deficiencies in shotcrete applications usually fall into one of four categories: failure to bond to the receiving substrate, delamination at construction joints or faces of the application layers, incomplete filing of the material behind the reinforcing, and embedment of rebound or other unsatisfactory material." (Warner, 1995).

Each of the above-listed deficiencies has occurred on Reclamation repair projects. Perhaps more important with shotcrete than with any other standard concrete repair method, if highly qualified, well trained, and competent workmen cannot be employed, it is advisable to consider using some other repair procedure. The quality of shotcrete closely depends upon the skill and experience of one person, the nozzleman. Reclamation specifications require employment of only formally certified nozzlemen for shotcrete repairs. The on-the-job training necessary to develop the experience and skill needed to achieve such certification for Reclamation work should occur prior to the nozzleman's arrival at the job.

(a) Preparation.—Concrete to be repaired with shotcrete should be prepared in a manner identical to the preparation required for replacement concrete, section 29.(a). Experience indicates, however, that surface preparation for shotcrete repair is more critical than for replacement concrete. It is essential with shotcrete repairs that the shotcrete have a clean, sound concrete base for bond.

(b) Materials.—Cement used for shotcrete should meet the same requirements as cement used for replacement concrete, section 29.(b). If sulfate exposure conditions exist, type V portland cement should be specified. Normally, however, type I-II, low alkali cement is adequate. Water, sand, and coarse aggregate used in shotcrete should also meet the requirements for replacement concrete, except that the maximum size coarse aggregate should not exceed 3/8 of an inch.

Additives for shotcrete should meet the requirements of ASTM designation C 494, Chemical Admixtures for Concrete. It is normally not possible to accomplish air entrainment with dry mix shotcrete. Lack of air entrainment may lead to dry mix shotcrete having lower than desired freeze-thaw resistance. Wet mix shotcrete should be proportioned to contain 6 to 8 percent entrained air.

It is sometimes desirable to use accelerating admixtures in shotcrete where rapid setting or rapid strength development is required. Calcium chloride accelerators have long been used, but there are now sufficient non-chloride containing accelerators in the market- place to make the use of calcium chloride inadvisable. The use of calcium chloride accelerators is particularly unadvisable in shotcrete applications containing reinforcing steel or steel fibers.

Fiber reinforcement has been used in shotcrete since the early 1970s, and the M-47 specifications in appendix A contain specifications for steel fiber reinforcement. The American Concrete Institute has published a state of the art report on fiber reinforced shotcrete (American Concrete Institute, 1984), and this document should be consulted if the use of fiber reinforced shotcrete is being considered. It should be recognized that application of fiber reinforced shotcrete is more difficult and requires more experienced nozzlemen.

(c) Application.—The detailed discussion of shotcrete application techniques and technology is beyond the scope of this guide. The American Concrete Institute has published a recommended practice and a specification for materials, proportioning, and application of shotcrete (American Concrete Institute, 1966; 1977). These documents should be studied before attempting shotcrete repairs.

(d) Curing.—Proper curing of shotcrete is essential if high strength properties, durability, and long service life are to be obtained. The M-47 specifications permit water curing or curing of shotcrete by application of curing compounds. It is important to begin curing by applying approved curing compounds or water spray before there has been evaporative water loss from the shotcrete, particularly during periods of high temperatures, low humidity, or high wind conditions. Improvements in bond strength will be obtained by continuing curing for periods of up to a month.

29. Replacement Concrete.—Concrete repairs made by bonding new concrete to repair areas without use of an epoxy bonding agent or mortar grout applied on the prepared surface should be made when the area exceeds 1 square foot and has a depth greater than 6 inches and when the repair will be of appreciable continuous area. Replacement concrete repairs should also be used for:

- Holes extending entirely through concrete sections

- Holes in which no reinforcement is encountered, or in which the depth extends 1 inch below or behind the backside of the reinforcing steel and which are greater in area than 1 square foot and deeper than 4 inches, except where epoxy- bonded concrete replacement is required or permitted as an alternative to concrete replacement

- Holes in reinforced concrete greater than one-half square foot and extending beyond reinforcement

Replacement concrete is the most common concrete repair material and will meet the needs of a majority of all concrete repairs. Replacement concrete repairs are made by bonding new concrete to the repair areas without the use of a bonding agent or portland cement grout. The combination of a deep repair and good curing practices ensures adequate hydration water will remain at the bonding surface zone for at least 28 days, allowing the cement hydration process to develop good bond. Because the defective concrete is being replaced with high quality concrete very similar to the surrounding concrete, the repair is compatible in thermal expansion and in other physical and chemical properties with the old concrete. For this reason, in many cases, the best repair method is the use of replacement concrete. Only when an unusual increase in durability is needed, or when placing conditions or dimensions dictate otherwise, should other materials be considered.

(a) Preparation.—To obtain satisfactory results with the replacement concrete method, preparation should be as follows:

- Reinforcement bars should not be left partially embedded; concrete should be removed to provide a clearance of at least an inch around each bar exposed more than one-third its circumference.

- The perimeter of the hole at the face should be saw cut to a minimum depth of 1 inch. If the shape of the defect makes it advisable, the remainder of the concrete removal may be chipped below the vertical saw cut and continued until a horizontal surface is obtained. The top of the hole, if on a vertical wall, should be cut on a 1:3 upward slope from the back toward the face from which the concrete will be placed (see figure 14). This is essential to permit vibration of the concrete without leaving air pockets at the top of the repair. In some instances, where a hole extends through a wall or beam, it may be necessary to fill the hole from both sides; the slope of the top of the cut should be modified accordingly.

- The bottom and sides of the hole should be cut sharply and approximately square with the face of the wall. When the hole extends through the concrete section, spalling and feather edges must be avoided by having perimeter saw cuts from both faces. All interior corners should be rounded to a minimum radius of 1 inch.

- For repairs on surfaces subject to destructive water action and for other repairs on exposed surfaces, the outlines of areas to be repaired should be saw cut as directed to a depth of 1-1/2 inches before the defective concrete is excavated. The new concrete should be secured by keying methods. Figure 47 shows a vertical wall being prepared for replacement concrete repairs.

The construction and setting of forms are important steps in the procedure for satisfactory concrete replacement where the concrete must be placed from the side of the structure. Form details for walls are shown in figure 48. To obtain a tight and acceptable repair, the following requirements must be observed:

- Front forms for wall repairs more than 18 inches high should be constructed in horizontal sections so the concrete can be conveniently placed in lifts not more than 12 inches deep. The back form may be built in one piece. Sections to be set as concreting progresses should be fitted before placement is started.

- To exert pressure on the largest area of form sheathing, tie bolts should pass through wooden blocks fitted snugly between the walers and the sheathing.

- For irregularly shaped holes, chimneys may be required at more than one level; when beam connections are required, a chimney may be necessary on both sides of the wall or beam. For such construction, the chimney should extend the full width of the hole.

- Forms should be substantially constructed so that pressure may be applied to the chimney cap at the proper time.

- Forms must be mortar tight at all joints between adjacent sections, between the forms and concrete, and at tie bolt holes to prevent the loss of mortar when pressure is applied during the final stages of placement. Twisted or stranded caulking cotton, folded canvas strips, or similar material should be used as the forms are assembled.

Surfaces of old concrete to which new concrete is to be bonded must be clean, rough, and in a saturated surface dry condition. Extraneous material on the joint resulting from form construction must be removed prior to placement.

(b) Materials.—Concrete for repair should have the same water-cement ratio as used for similar new structures but should not exceed 0.47, by weight. Aggregate of as large a maximum size and slump as low as is consistent with proper placing and thorough vibration should be used to minimize water content and consequent shrinkage. The concrete should contain 3 to 5 percent entrained air. Where surface color is important, the cement should be carefully selected or blended with white cement to obtain the desired results. To minimize shrinkage, the concrete should be as cool as practicable when placed, preferably at about 70 °F or lower. Materials should, therefore, be kept in shaded areas during warm weather. Use of ice in mixing water may sometimes be necessary. Batching of materials should be by weight; but batch boxes, if of the exact size needed, may be used. Since batches for this class of work will be small, the uniformity of the materials is important and should receive proper attention.


Figure 47.—Preparation of a wall for placement of replacement concrete repairs.

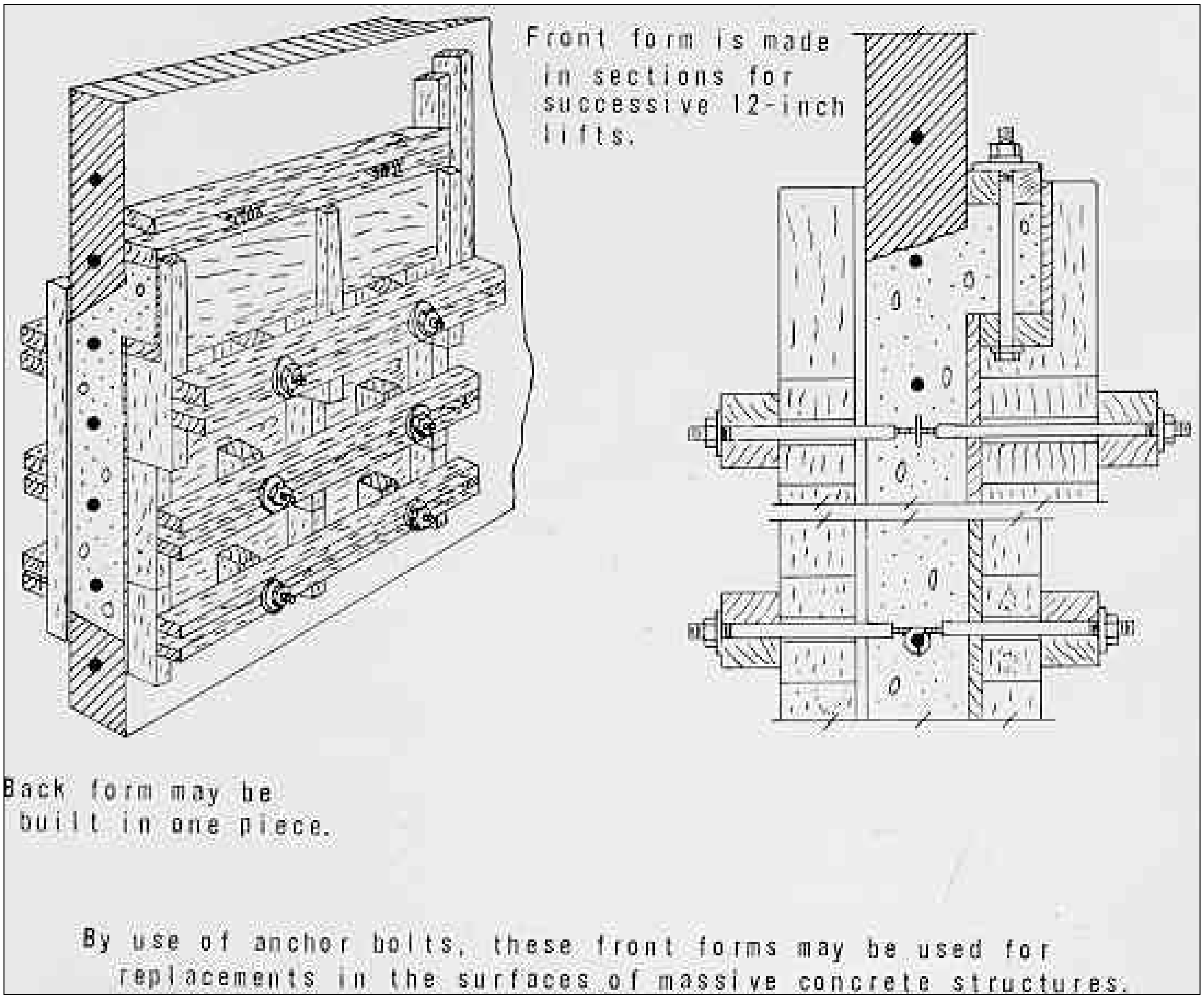

Figure 48.—Detail of forms for concrete replacement in walls.

Best repairs are obtained when the lowest practicable slump is used. This is about 3 inches for the first lift in an ordinary large form. Subsequent lifts can be drier, and the top few inches of concrete in the hole and that in the chimney should be placed at almost zero slump. It is usually best to mix enough concrete at the start for the entire hole. Thus, the concrete will be up to 1-1/2 hours old when the successive lifts are placed. Such premixed concrete, provided it can be vibrated satisfactorily, will have less settlement, less shrinkage, and greater strength than freshly mixed concrete.

Structural concrete placements should be started with an oversanded mix containing about a 3/4-inch-maximum size aggregate; a maximum water-cement ratio of 0.47, by weight; 6 percent total air, by volume of concrete; and having a maximum slump of 4 inches. This special mix should be placed several inches deep on the joint at the bottom of the placement. A mortar layer should not be used on the construction joints.

(c) Application.—When placing concrete in lifts, placement should not be continuous; a minimum of 30 minutes should elapse between lifts. When chimneys are required at more than one level, the lower chimney should be filled and allowed to remain for 30 minutes between lifts. When chimneys are required on both faces of a wall or beam, concrete should be placed in only one of the chimneys until it flows to the other. Attempted placement in both chimneys will result in air entrapment and/or voids in the structure.

The quality of a repair depends not only on use of low-slump concrete, but also on the thoroughness of the vibration during and after depositing the concrete. There is little danger of overvibration. Immersion-type vibrators should be used if accessibility permits. If not, this type of vibrator can be used very effectively on the forms from the outside. Form vibrators can be used to good advantage on forms for large inaccessible repairs, especially on a one-piece back form, or attached to large metal fittings such as hinge-base castings. Immediately after the hole has been completely filled, pressure should be applied to the fill and the form vibrated. This operation should be repeated at 30-minute intervals until the concrete hardens and no longer responds to vibration. Pressure is applied by wedging or by tightening the bolts extending through the pressure cap (figure 48). In filling the top of the form, concrete to a depth of only 2 or 3 inches should be left in the chimney under the pressure cap. A greater depth tends to dissipate the pressure. After the hole has been filled and the pressure cap placed, the concrete should not be vibrated without a simultaneous application of pressure. To do so may pro-duce a film of water at the top of the repair that will prevent bonding.

Addition of aluminum powder to concrete causes the latter to expand as described in section 182 of the *Concrete Manual* (Bureau of Reclamation, 1975). Under favorable conditions, this procedure has been successfully used to secure tight, well-bonded repairs in locations where the replacement material had to be introduced from the side. Forms similar to those shown in figure 48 should be used. Time should not be allowed for settlement between lifts. When the top lift and the chimney are filled, no pressure need be applied, but the pressure cap should be secured in position so expanding concrete will be confined to and completely fill the hole undergoing repair. There should be no subsequent revibration.

Concrete replacement in open-top forms, as used for reconstruction of the tops of walls, piers, parapets, and curbs, is a comparatively simple operation. Only such materials as will make concrete of proved durability should be used. The water-cement ratio should not exceed 0.47, by weight. For the best durability, the maximum size of aggregate should be the largest practicable and the percentage of sand the minimum practicable. No special features are required in the forms, but they should be mortar tight when vibrated and should give the new concrete a finish similar to the adjacent areas. The slump should be as low as practicable, and dosage of air entraining agent should be increased as necessary to secure the maximum permissible percentage of entrained air, despite the low slump. Top surfaces should be sloped to provide rapid drainage. Manipulation in finishing should be held to a minimum, and a wood-float finish is preferable to a steel-trowel finish. Edges and corners should be tooled or chamfered. Use of water for finishing is prohibited.

Forms for concrete replacement repairs usually may be removed the day after casting unless form removal would damage the green concrete, in which event stripping should be postponed another day or two. The projections left by the chimneys normally should be removed the second day. If the trimming is done earlier, the concrete tends to break back into the repair. These projections should always be removed by working up from the bottom because working down from the top tends to break concrete out of the repair. The rough area resulting from trimming should be filled and stoned to produce a surface comparable to that of surrounding areas. Plastering of these surfaces should never be permitted.

Some replacement concrete does not require forms. Replacement of damaged or deteriorated paving or canal lining slabs, wherein the full depth of the slab is replaced, involves procedures no different from those required for best results in original construction. Contact edges at the perimeter should be saw cut clean and square with the surface.

Special repair techniques are required for restoration of damaged or eroded surfaces of spillway or outlet works tunnel inverts and stilling basins. In addition to the usual forces of deterioration, such repairs often must withstand enormous dynamic and abrasive forces from fast-flowing water and sometimes from suspended solids. Silica fume concrete (section 37) is the repair material of choice for these types of repair. Whenever practicable, low slump silica fume concrete should be used. Slump of the concrete should not exceed 2 inches for slabs that are horizontal or nearly horizontal and 3 inches for all other concrete. (Note: This is 1 inch less slump than that permitted in the M-47 specifications for conventional applications of silica fume concrete.) The net water-cementitious ratio (exclusive of water absorbed by the aggregates) should not exceed 0.35 by weight. An air-entraining agent and a high range water reducing admixture should be used. Set- retarding admixtures should be used only when the interval between mixing and placing is quite long. (These recommendations are repeated in section 37.)

If, however, needed repairs are too small for the replacement concrete method (including silica fume concrete), they should be made using the dry pack procedure (section 26), the epoxy-bonded epoxy mortar method, (section 30) or the epoxy-bonded replacement concrete method (section 31).

(d) Curing and Protection.—The importance of curing replacement concrete repairs cannot be overemphasized. Complete failure of repairs has been attributed to inadequate or improper curing. There is no known condition short of flooding the repaired structure (which in itself is an excellent curing method) that does not require curing of cementitious repairs. Because of the relatively small volume of most repairs and the tendency of old concrete to absorb moisture from new material, water curing is a highly desirable procedure, at least during the first 24 hours. When forms are used for repair, they can be removed and then reset to hold a few layers of wet burlap in contact with new concrete. One of the best methods of water curing is a soil- soaker hose laid beneath a plastic membrane covering the repair area.

When curing compound is used, the best curing combination is an initial water-curing period of 7 days (never less than 24 hours) followed, while the surface is still damp, by a uniform coat of the compound. It is always essential that repairs, even dry packed cone bolt holes, receive some water curing and be thoroughly damp before the curing compound is applied. If nothing better can be devised for the initial water curing of the dry pack in cone bolt holes and similar repairs, a reliable workman should be detailed to make the rounds with water and a large brush or a spraying device to keep the repaired surfaces wet for 24 hours prior to application of a curing compound. White curing compound may be used only where its color does not create objectionable contrast in appearance.

30. Epoxy-Bonded Epoxy Mortar.— Epoxy-bonded epoxy mortar should be used where the depth of repair is less than 1-1/2 inches and the exposure conditions are such that *relatively constant temperatures* can be expected. Epoxy mortars have thermal coefficients of expansion that may be significantly different from conventional concrete. If such mortars are used under conditions of wide and frequent temperature fluctuations, they will cause failure just below the bond surface in the base concrete. *For this reason, current Reclamation practice precludes the use of epoxy mortars under conditions of frequent or large temperature fluctuations.*

The application of epoxy mortar to repair areas of concrete deterioration caused by corroding reinforcing steel is also not recommended. The epoxy bond coat and epoxy mortar create zones of electrical potential that are different from the electrical potential in the surrounding concrete. This difference in potential can result in the formation of a galvanic corrosion cell with accelerated corrosion at the repair perimeters.

Epoxy mortar is properly used to make thin repairs (1/2-inch to 1-1/2-inch thickness) to concrete under relatively constant temperature exposure conditions. Such applications could include tunnel linings, indoor or interior concrete, the underside of concrete structures such as bridge decks, continuously inundated concrete such as stilling basin floors, canal linings below water line, or concrete pipe. Applications to concrete exposed to the daily temperature fluctuations caused by exposure to direct sunlight *are not appropriate for epoxy mortar repair*.

Properly applied epoxy mortar repairs have a long history of successful performance on Reclamation concrete when used under appropriate conditions. A 1991 inspection of the epoxy mortar repairs made at Yellowtail Dam in 1968 showed that less than 2 percent of the repairs had suffered failure in over 20 years of service. This is considered outstanding performance for a repair material.

(a) Preparation.—Concrete to be repaired with epoxy mortar should be prepared in accordance with section 8. Prior to application of the epoxy mortar, the concrete should be heated in sufficient depth, when necessary, so that the surface temperature (as measured by a surface temperature gage) does not drop below 40 EF during the first 4 hours after placement of an epoxy bond coat. This may require several hours of preheating with radiant heaters or other approved means (figures 49 and 50). If existing conditions prohibit meeting these temperature requirements, suitable modifications should be adopted upon the approval of the inspector or other responsible official. The concrete temperature during preheating should never exceed 200 EF, and the final surface temperature at the time of placing epoxy materials should never be greater than 100 EF.

(b) Materials.—Epoxy resins used to prepare epoxy mortar for use in concrete repair should be two-component, 100-percent solids type meeting the requirements of specification ASTM C-881 for type III, grade 2, class B or C. Class B epoxy is used between 40 and 60 EF. Class C epoxy is used above 60 EF up to the highest temperature defined by the epoxy manufacturer. The sand used in epoxy mortar must be clean, dry, well graded, and composed of sound particles. For most applications, sand passing a No. 16 screen and conforming to the following limits should be used:

Screen number	Individual percent, by mass, retained on screen
30	26 to 36
50	18 to 28
100	11 to 21
Pan	25 to 35

Range shown is applicable when 60 to 100 percent of pan is retained on No. 200 screen. When 41 to 100 percent of pan passes the No. 200 screen, the percent pan should be within the range of 10 to 20 percent, and the individual percentages retained on the Nos. 30, 50, and 100 screens should be adjusted accordingly.

Sand processed for use in concrete rarely contains the required quantity of pan size sand. As a result, problems often arise in obtaining additional pan size material to supplement sand available on the jobsite. A source of silica pan size material may be obtained by contacting the Materials Engineering and Research Laboratory, Code D-8180, Bureau of Reclamation, Denver Federal Center, Denver, Colorado 80225. A sand graded as shown above and properly mixed with an epoxy meeting ASTM C-881 specifications will provide a dense, high strength, workable epoxy mortar.

Figure 49.—A gas-fired forced air heater is being used to heat concrete prior to application of epoxy mortar.

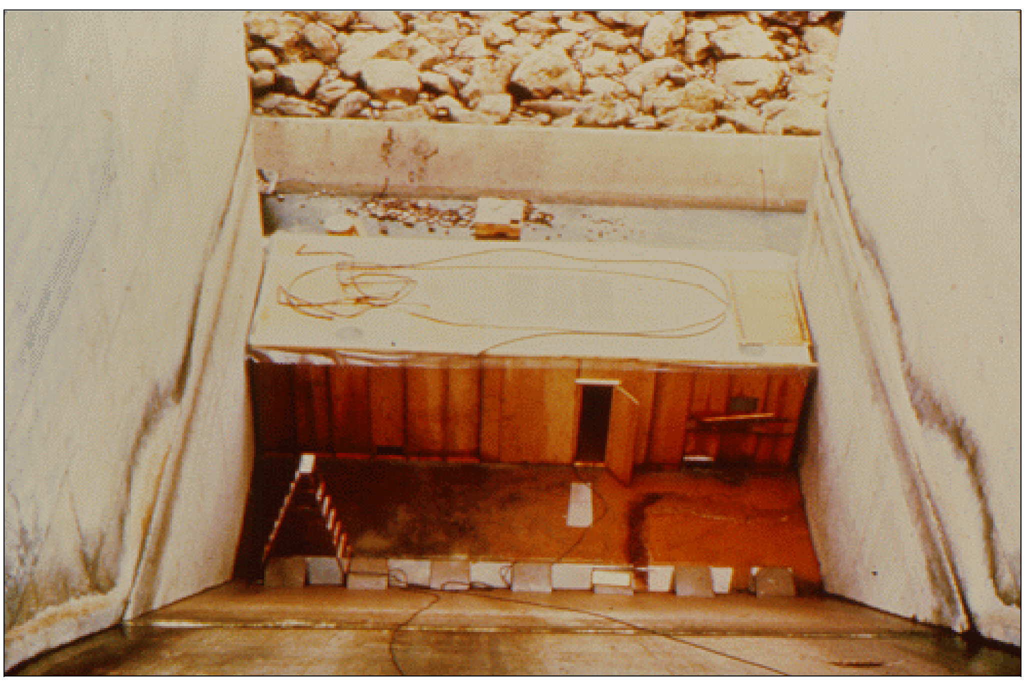

Figure 50.—An enclosure has been constructed over an area to be repaired with epoxy mortar to keep the concrete warm.

The sand should be maintained in a dry area at not less than 70 EF for 24 hours immediately prior to the time of use. Filler materials other than sand, such as portland cement, can be used. However, for general applications, a natural sand is recommended.

It is also acceptable to obtain and use brand name prepackaged epoxy mortar repair systems that contain resin and sand, *provided that the resin systems meet the ASTM C-881 specifications previously listed*. Such mortar systems are manufactured specifically for concrete repair and must be used in exact accordance with the manufacturer's recommendations.

On critical repair jobs such as areas of high velocity flow or on repairs requiring a considerable quantity of materials, the contractor should be required to submit samples of epoxy resin and graded sand to the Materials Engineering and Research Laboratory, Denver, for use in mix design determinations. The samples should consist of 1 gallon total quantity of epoxy components and a minimum of 50 pounds of graded sand. Samples should be submitted at least 30 days prior to use in the work and be labeled or otherwise identified with the specifications number under which the material is to be used.

(c) Mixing.—Preparation of epoxy mortar involves premixing proper quantities of epoxy resin and hardener and then mixing the resin system with sand to make the epoxy mortar.

The epoxy resin used for mortar preparation is a two-component (part A and part B) material which requires accurate combination of components and mixing prior to use. Once mixed, the material has a limited pot life and must be used immediately. (Pot life refers to the period of time elapsing between mixing of ingredients and their stiffening to the point where satisfactory use cannot be achieved.) The repair resin should be prepared by adding the required quantity of hardener (normally, part B) to the resin (normally part A) in proportions recommended by the manufacturer, followed by thorough mixing. Since the pot life of the mixture depends on the temperature (longer at low temperature, much shorter at high temperature), the quantity to be mixed at one time should be that quantity that can be applied within approximately 30 minutes. The addition of nonreactive thinners or diluents to the resin mixture is not permitted since it weakens the epoxy.

The epoxy mortar is composed of sand and epoxy resin suitably blended to provide a stiff, workable mix. Mix proportions should be established, batched, and reported on a weight basis, although the dry sand and mixed epoxy may be batched by volume using suitable measuring containers that have been calibrated on a weight basis. Epoxy meeting ASTM specification C-881 will require approximately 5-1/2 to 6 parts of graded sand to 1 part epoxy, by weight. This is equivalent to a ratio of approximately 4 to 4-1/2 parts sand to 1 part epoxy, by volume. If equivalent volume proportions are being used, care must be taken to prevent confusing them with weight proportions. It will be necessary to adjust the mix proportions for the particular epoxy and sand being used. The epoxy mortar should be thoroughly mixed with a slow-speed mechanical device. The mortar should be mixed in small size batches so that each batch can be completely mixed and placed within approximately 30 minutes. Figure 51 shows a simple bucket mixer that is adequate to mix epoxy mortar for small repairs.

(d) Application.—Application of epoxy mortar repairs first requires application of a resin bond coat followed by application and finishing of the epoxy mortar. Surfaces of existing concrete to which epoxy mortar is to be bonded should be prepared as discussed in section 8. Steel to be embedded in epoxy mortar should be prepared, cleaned, and dried in the same manner as the concrete being repaired. The exposed steel should be completely coated with epoxy bonding agent when the agent is applied to the surfaces of the repair area.

A resin bond coat consisting of the same type epoxy resin used to mix the epoxy mortar is applied to the prepared concrete surface immediately before placing the epoxy mortar. After the bond coat resin is mixed, it must be uniformly applied to the prepared, dry, existing concrete at a coverage of not more than 80 square feet per gallon, depending on surface conditions. The area of coverage per gallon of resin depends on the roughness of the surface to be covered and may be considerably less than the maximum specified. The epoxy bonding agent may be applied by any convenient, safe method such as

Figure 51.—A bucket mixer can be used to mix epoxy mortar for small repair areas.

squeegee, brushes, or rollers which will yield an effective coverage. Spraying of the material is permitted if an efficient airless spray is used and if the concrete surfaces to receive the agent are at a temperature of 70 EF or some-what warmer. Before approving spraying, it should be demonstrated that spraying will provide an adequate job with minimum overspray. If spray application is used, the operator must wear a compressed air-fed hood, and no other personnel should be closer than 100 feet if downwind of the operator.

During application of the epoxy bond coat, care must be exercised to confine the material to the area being bonded and to avoid contamination of adjacent surfaces. However, the bond coat should extend slightly beyond the edges of the repair area.

The applied epoxy bonding resin must be in a fluid condition when the epoxy mortar is placed. If the resin cures beyond this fluid state but is still tacky, a second bond coat should be applied over the first coat. If any bond coat has cured beyond the tacky state, it must be completely removed by sandblasting, the concrete properly cleaned, and a new bond coat applied.

Special care must be taken to prevent the bond coat from being spread over concrete surfaces not properly cleaned and prepared.

Appropriate solvents may be used to clean tools and spray guns, but in no case should the solvents be incorporated in any bonding agent. All tools must be completely dried before reuse.

The prepared epoxy mortar should be tamped, flattened, and smoothed into place (figure 52) in all areas while the bonding resin is still in a fluid condition, except that on steep slopes, the bond coat can be allowed to stiffen to a very tacky condition to assist in holding the mortar in place. Special care must be taken to thoroughly compact the epoxy mortar against the bond coat. The mortar should be worked to grade and given a steel trowel finish (figure 53). Special care must be taken at the edges of the area being repaired to assure complete filling and leveling and to prevent the mortar from being spread over surfaces not having the epoxy bond coat application. Steel troweling should best suit prevailing conditions; in general, it should be performed by applying slow, even strokes. Trowels may be heated to facilitate the finishing, but the use of thinner, diluents, water, or other lubricants on placing or finishing tools is not permitted. After leveling the epoxy mortar to the finished grade where precision surfaces are required on sloping, vertical, or overhead surfaces, the mortar should be covered with plywood panels smoothly lined with polyethylene sheeting and weighted with sandbags or otherwise braced by suitable means until the possibility of slumping has passed. When polyethylene sheeting is used, no attempt should be made to remove it from the epoxy mortar repair before final hardening.

Surfaces of all epoxy mortar repairs should be finished to the plane of surfaces adjoining the repair areas. The final finished surfaces should have the same smoothness and texture of surfaces adjoining the repair areas.

(e) Curing.—Epoxy mortar repairs should be cured immediately after completion at not less than the temperature range prescribed by the class of the epoxy until the mortar is hard. Postcuring, if required by the specifications, can then be initiated at elevated temperatures by heating in depth the epoxy mortar and the concrete beneath the repair. Postcuring should continue for a minimum of 4 hours at a surface temperature generally not less than 90 EF nor more than 110 EF. The heat could be supplied by use of portable propane-fired heaters, infrared lamp heaters, or other approved sources positioned to attain the required surface temperatures (figure 54).

In no case should epoxy-bonded epoxy mortar be subjected to moisture until after the specified postcuring has been completed.

Epoxy mortars generally produce patches that are darker than the surrounding concrete.

Figure 52.—Epoxy mortar is consolidated and compacted by hand tamping.

Figure 53.—Applying the steel trowel finish required by epoxy mortar repairs.

Figure 54.—Postcuring heating enclosure installed over an epoxy mortar repair area.

Some available epoxies produce a gray- colored mortar resembling concrete. However, these materials will rarely produce an exact color match. Grinding hardened epoxy mortar may lighten its color to about that of the surfaces adjoining the repair areas. Epoxy mortars can be colored by the addition of such materials as iron oxide red, chromium oxide green, lampblack and titanium dioxide white for gray, and ocher yellow; although Reclamation rarely uses any materials to color the epoxy other than the sand for the mortar. Use of white silica sand in the mortar will produce a white-looking patch; most natural riverborne sands will produce darker colored mortars. Whenever epoxy mortar repair materials must be colored to match adjacent concrete, laboratory mixes should be made to ascertain the proper quantities of coloring constituents.

(f) Safety.—All personnel must be carefully instructed to take every precaution in preventing epoxy resins and their components from contacting the skin and in preventing the breathing of epoxy fumes or vapors. Protec-tive clothing must be worn, including gloves and goggles, and protective creams for other exposed skin areas should be provided when handling epoxies, as severe allergic reactions and possible permanent health damage can result when these materials are allowed to contact and remain upon the skin. Any deposits acquired through accidental contact of these materials with unprotected skin must be removed immediately by washing with soap and water, never with solvents. Solvents, such as toluene and xylene, may be used only for cleaning epoxy from tools and equipment. Care must also be exercised to avoid contact of cleaning solvents with the skin and to provide adequate ventilation for mixing, placing, and cleanup operations. All safety equipment used must conform to the requirements of the Occupational Safety and Health Standards of the Occupational Safety and Health Administration.

31. Epoxy-Bonded Replacement Concrete.— Epoxy-bonded concrete is used for repairs to concrete that are between 1.5 and 6 inches thick. Shallow replacement concrete repairs, less than 6 inches thick, are subject to poor curing conditions as a result of moisture loss to evaporation and to capillary absorption by the old base concrete. Such repairs seldom develop acceptable bond strength to the old concrete.

The epoxy bonding resin is used to ensure a strong, durable bond between the old concrete and the replacement concrete.

As with epoxy-bonded epoxy mortar, care should be exercised if epoxy-bonded concrete is to be used to repair shallow deterioration resulting from corroding reinforcement. The epoxy bond coat may create electrical potentials sufficiently different from potentials in the surrounding concrete to result in accelerated corrosion at repair perimeters.

(a) Preparation.—Concrete to be repaired with epoxy-bonded concrete must be prepared as described in section 8.

(b) Materials.—The materials used in epoxy-bonded concrete repairs consist of conventional portland cement concrete and epoxy resin bonding agent.

The concrete used for epoxy-bonded repairs is the same as that used for replacement concrete repairs (section 29) except that the slump of the concrete when placed should not exceed 1-1/2 inches.

A number of proprietary epoxy formulations prepared for bonding new concrete to old concrete are now available. Many of these materials are excellent high quality products and can be used with reasonable certainty as to the results. However, some of the resins available are unsuitable or untested for such repair applications, and care should be taken to use only the epoxy bonding resins meeting the requirements of specification ASTM C-881 for a type II, grade 2, class B or C epoxy system. Class B epoxy should be used when the temperatures are above 40 EF but less than 60 EF. Class C epoxy should be used when concrete temperatures are from 60 EF up to the maximum temperature recommended by the epoxy manufacturer.

The epoxy resin used for epoxy-bonded concrete is a two component, 100-percent solids resin system requiring accurate proportioning and thorough mixing prior to use. The procedures described in section 30 should be followed during preparation and application of the resin. Conventional concrete mixing procedures as described in section 29 should be followed to mix the concrete.

(c) Application.—Use of epoxy-bonded concrete in repairs requiring forming, such as on steeply sloped or vertical surfaces, can be permitted only when sufficient time has been allowed to place concrete against the epoxy bonding resin while it is still fluid. If the resin cures before placement of the concrete, no bond will develop between the old and new concrete. It is a good idea to practice install such forms at least once before actually applying the epoxy bond coat (figure 55).

Immediately after application of the epoxy resin bonding agent and while the epoxy is still fluid, unformed epoxy-bonded concrete should be spread evenly to a level slightly above grade and compacted thoroughly by vibrating or tamping (figure 56). Tampers should be sufficiently heavy for thorough compaction. After being compacted and screeded, the concrete should be given a wood-float or steel-trowel finish as required. Water, cement, or a mixture of dry cement and sand should never be sprinkled on the surface. Troweling, if required, should be performed at the proper time and with heavy pressure to produce a smooth, dense finish free of defects and blemishes. As the concrete continues to harden, the surface should be given additional trowelings.

The final troweling should be performed after the surface has hardened so that no cement paste will adhere to the edge of the trowel, but excessive troweling cannot be permitted.

(d) Curing.—Even though an epoxy bond coat is used, it still remains essential to properly cure epoxy-bonded concrete. As soon as the epoxy-bonded concrete has hardened sufficiently to prevent damage, the surface should be cured by spraying lightly with water and then covering with sheet poly-ethylene or by coating with an approved curing compound.

Figure 55.—If forms are required for epoxy-bonded concrete repairs, they should be installed at least once prior to application of the epoxy bond coat to ensure that they fit as planned and that they can be installed and filled before the bond coat hardens.

Figure 56.—The placement techniques for epoxy-bonded concrete are essentially the same as for conventional concrete.

Curing compound should be used whenever there is any possibility that freezing temperatures will prevail during the curing period. Sheet polyethylene must be an airtight, nonstaining, waterproof covering that will effectively prevent evaporation. Edges of the polyethylene should be lapped and sealed. The waterproof covering should be left in place for at least 2 weeks. If a waterproof covering is used and the concrete is subjected to any usage during the curing period that might rupture or otherwise damage the covering, the covering must be protected by a suitable layer of clean, wet sand or other cushioning material that will not stain concrete. Application of curing compound must be in accordance with appropriate standard procedures as contained in the *Concrete Manual* (Bureau of Reclamation, 1975).

(e) Safety.—All personnel must be carefully instructed to take every precaution in preventing epoxy resins and their components from contacting the skin and in preventing the breathing of epoxy fumes or vapors. Protective clothing must be worn, including gloves and goggles, and protective creams for other exposed skin areas should be provided when handling epoxies, as severe allergic reactions and possible permanent health damage can result when these materials are allowed to contact and remain upon the skin. Any deposits acquired through accidental contact of these materials with unprotected skin must be removed immediately by washing with soap and water, never with solvents. Solvents, such as toluene and xylene, may be used only for cleaning epoxy from tools and equipment. Care must also be exercised to avoid contact of cleaning solvents with the skin and to provide adequate ventilation for mixing, placing, and cleanup operations. All safety equipment used must conform to the requirements of the Occupational Safety and Health Standards of the Occupational Safety and Health Administration.

32. Polymer Concrete.—Polymer concrete (PC) is a concrete system composed of a polymeric resin binder and fine and coarse aggregate. Water is not used to mix polymer concrete. Instead, the liquid resin, known as a monomer, is caused to cure or harden by a chemical reaction known as polymerization. During polymerization, the monomer molecules are chemically linked and cross linked to form a hard, glassy plastic known as a polymer. The polymers used in PC are formulated to provide the special properties needed for high performance repair materials. These systems can be cured very quickly and are most useful in performing repairs to structures that must be immediately returned to service. As an example, PC is commonly used to repair potholes in concrete highway bridge decks, thereby eliminating the necessity of long and costly road closures or detours. It is also useful for repairs to structures, such as tunnel linings, that can be maintained in a dry condition for only short periods of time and for cold weather repairs down to temperatures as low as 15 EF. PC repairs can be accomplished in thicknesses varying from about 1/2 inch to several feet if appropriate precautions are taken.

PC develops strength and durability properties very quickly due to its rapid polymerization characteristics and is useful where rapid repairs to concrete are required. PC can be mixed, placed, polymerized, and put into service in only a matter of hours. PC also develops enhanced durability properties. This feature makes it useful as protective overlays on conventional concrete exposed to corrosive or severe environments. Since PC does not contain mix water, it can be used at much lower temperatures (down to 15 EF) than portland cement concrete.

Most polymer concretes experience some volumetric shrinkage during polymerization and also have problems associated with the coefficient of thermal expansion similar to those experienced with epoxy mortars. These problems with PC, though generally less severe than similar problems with epoxy mortar, can limit the materials use on concrete exposed to wide temperature variations. Potential users of PC should be aware of these problems. The Materials Engineering and Research Laboratory at Denver, D-8180, can provide guidance and recommendations for the application of these very useful materials.

(a) Preparation.—Concrete preparation for PC repairs should be in accordance with section 8. Although some manufacturers indicate that PC may be used for feather edge repairs, Reclamation experience is otherwise. Saw cut repair perimeters are required if high quality repairs are to be achieved. Special care should be taken to ensure the base concrete is dry prior to application of the repair material. Once the PC is in place, this requirement can be relaxed. However, flowing water may remove the fresh polymer concrete if allowed on the concrete prior to development of initial set.

(b) Materials.—A number of manufacturers have developed prepackaged PC systems. Most of the systems consist of acrylic or vinyl ester monomers, appropriate polymerization initiators and catalysts, and fine aggregate and fillers. It is common for the user to extend the polymer concrete, particularly when used to fill depressions deeper than 1 inch, by supplying and adding coarse aggregate to the prepackaged PC system during mixing. The prepackaged polymer concretes also contain monomer bond coat systems that must be mixed and applied to the base concrete prior to application of the polymer concrete mixture.

(c) Application.—Each manufacturer of prepackaged PC provides detailed instructions for proportioning, mixing, and applying its product. These instructions must be closely followed to obtain a satisfactory repair.

A bond coat monomer system is mixed and applied to the prepared concrete prior to application of the PC. Care must be taken to proportion and mix the bond coat components properly. Some manufacturers specify that the bond coat be applied and cured prior to placing the polymer concrete. Others specify that the polymer concrete be applied while the bond coat is still in the liquid state. It is important to follow the procedures recommended by the manufacturer of the product actually being used.

Polymer concrete can be mixed in paddle-type, rotary drum-type, or other types of power equipment suitable for mixing conventional concrete. Very small quantities of PC can even be mixed in the original shipping containers. Three minutes of mixing time should be adequate for all the prepackaged systems. It is common practice to first add the dry powder and aggregate components to the mixer and then add the liquid resin. With some systems, the liquid component may require a separate premixing step to combine the monomer with the catalyst or initiators needed for polymerization. Other manufacturers include the initiators in the powder-fine aggregate component, thereby eliminating the premixing requirement.

The mixed PC is placed just like conventional concrete, using the same tools and procedures (figure 57). Most PC mixtures will be almost self-leveling and require only a minimum finishing operation. Light mechanical vibration should be provided to consolidate placements thicker than 2 to 3 inches (figure 58). Once the PC has been placed and consolidated, it should be screeded to proper grade and quickly finished with a wood or steel trowel. The top surface of the repair forms a "skin" soon after being placed. If repeated toweling is attempted, this skin will tear and cause an unsightly surface.

Polymer concrete develops a strong bond to most materials. If forms are used, they must be leakproof and provided with some method of bond breaker or release agent. Wrapping the forms with polyethylene film has proven a very effective method of preventing bond between the form and the PC.

(d) Curing.—Polymer concretes polymerize and harden very quickly under most ambient conditions and will develop nearly full strength within a 1- to 2-hour period. During this time, the fresh concrete must be protected from water and not disturbed (figure 59). If temperatures are lower than about 40 EF, the polymerization reaction will occur at a slower rate unless increased concentrations of initiator are used or the repair is heated to 70E to 80 EF. Conversely, polymerization can occur too quickly, with insufficient finishing time, if the ambient temperature exceeds 90E to 100 EF. A reduction of initiator concentration can reduce this problem. Alternately, the repairs can be made during the cooler parts of the day or at night.

(e) Safety.—All workers, supervisors, and inspectors involved with the project must be made aware of the procedures required for safe use of PC. The manufacturers of PC provide recommendations for safe storage, handling, and use. These recommendations must be known and followed by users of the materials. The following *minimum* safety requirements must be followed on Reclamation projects:

Storage.—Polymer concrete monomer and initiators are heat sensitive and flammable. These materials should be stored away from the direct rays of sunlight, in the original shipping containers, in well-ventilated areas away from sources of ignition. The storage temperature should not exceed 80 EF. Storage periods should not exceed manufacturer's recommendations.

Mixing and Handling.—Smoking, flame, or other sources of ignition must not be permitted during mixing and application. Electrical equipment in contact with polymer concrete should be grounded for safe discharge of static electricity. Type B or type ABC fire extinguishers must be provided at the storage, mixing, and application locations.

Personal Protective Equipment.—Workers using polymer concrete must be provided rubber boots and required to use disposable protective clothing. Splash-type safety goggles and impervious gloves must be provided to workers using polymer concrete, and the workers must be required to wear these items. In some instances where ventilation is poor or inadequate, workers may be required to wear organic vapor respirators. The mixing and application site should be provided with portable eyewash equipment capable of

Figure 57.—Placing polymer concrete in a repair area. Sandbags and polyethylene sheeting were used to prevent water from entering the repair area.

Figure 58.—Small stinger vibrators can be used to consolidate shallow depths of polymer concrete.

Figure 59.—Polymer concrete must be protected from water and not disturbed during the 1- to 2-hour curing period. No other curing procedures are required unless ambient temperatures are very low.

sustaining a 15-minute stream of clean, room temperature water.

33. Thin Polymer Concrete Overlay.—The thin PC overlay is a hard, glassy concrete coating, 25 to 50 mils thick, consisting of a vinyl ester resin system, silica flour filler, and appropriate coloring pigments. This membrane-forming overlay partially penetrates the immediate top surface of the concrete and provides very good protection to concrete exposed to adverse chemical or weathering conditions. It can also provide cosmetic treatment to concrete exposed to public view. The normal three-coat application of this material (one primer coat plus two filler coats) should result in a total overlay thickness of about 50 mils.

The overlay is applied to protect the concrete from water penetration and resulting freeze-thaw damage; to protect the concrete from chemical corrosive elements such as acids, chlorides, or sulfates; and/or to improve the cosmetic appearance of the concrete. The overlay provides complete opaque coverage of the concrete surface and flows into and seals narrow cracks in the surface. The thin PC overlay is a standard repair material specified in the *Standard Specifications for the Repair of Concrete, M-47* of appendix A. There is currently no known commercial manufacturer of the thin polymer concrete overlay. Contractors or users of the overlay system can have the material prepared by custom resin blenders or can blend and mix the material themselves using the formulas listed below.

(a) Preparation.—Concrete to receive the thin polymer concrete overlay must be cleaned and prepared using light hydroblasting or wet sandblasting in accordance with the requirements of section 8. The prepared concrete surfaces must then be maintained in a clean, dry condition until the placement of the thin overlay is completed. The dryness of the concrete can be checked by taping a clear polyethylene sheet onto the surface of the concrete in a sunlight exposure. If no moisture collects under the polyethylene sheet after an hour or two of sunlight, the surface is sufficiently dry.

(b) Materials.—The thin overlay is prepared with vinyl ester resin, polymerization initiator and promoter, silicon flour filler, and pigments.

Vinyl Ester.—The vinyl ester resin is Dow Derakane 8084, manufactured by Dow Chemical Co., 2800 Mitchell Drive, Walnut Creek, California 94596.

Initiator.—The initiator is cumene hydroperoxide-78 percent, manufactured by Lucidol Division, Penwalt Corp., 1740 Military Road, Buffalo, New York 14240, or equal.

Promoter.—The promoter is cobalt napthenate-6 percent, available from fiber-glass materials suppliers.

Filler.—The filler is ground silica, minus 45 micrometers (No. 355) sieve size, manufactured by Ottawa Silica Co., Ottawa, Illinois; or Silco Seal 395 Ground Silica, manufactured by VWR Scientific, PO Box 3200, San Francisco, California 94119.

Pigment.—Two pigments are required to obtain a concrete gray color.

Titanium dioxide powder, manufactured by VWR Scientific

Carbon lamp black or bone black powder (do not use activated carbon)

Mixing Proportions.—

Primer	5.0	gallons vinyl ester resin
	0.60	pounds initiator
	0.25	pounds promoter
Pigmented topcoats	5.0	gallons vinyl ester resin
	1.35	pounds initiator
	0.27	pounds promoter
	40.0	pounds filler
	4.00	pounds titanium dioxide pigment
	0.02	pounds carbon black pigment

Mixing Sequence.—The vinyl ester resin, filler, and pigments should be premixed and set aside for several hours to wet out before use. Immediately prior to application, the initiator is added and thoroughly mixed with the resin. Then, the promoter is added to the resin and thoroughly mixed. *Never directly mix initiator and promoter, or an extremely violent and explosive reaction will occur.*

(c) Application.—The thin polymer concrete overlay consists of one primer coat and one or two sealant coats applied at a coverage rate of 1.3 to 2.0 gallons of material per 100 square feet of surface per coat, depending on surface texture of the concrete. The material may be applied with brooms, brushes, or paint rollers (figure 60).

The primer must uniformly and completely cover the surface and should be scrubbed into the surface of the concrete, eliminating discontinuities and puddles. The pigmented topcoat(s) must be applied to the primed surface not less than 4 hours nor more than 24 hours after application of the primer or of a succeeding to coat. It is not desired that the primer or topcoat cure to a hard final finish before application of the succeeding topcoat. A somewhat tacky finish is more desirable. However, full bond between coats will be obtained by following the above-listed timeframe for application.

Caution must be exercised to prevent application of primer or topcoats not containing initiator, promoter, or both. A simple technique of reducing the possibility of this is to place containers of preweighed resin, initiator, and promoter at appropriate locations along the application route before the application begins. After the containers are preplaced, one workman can quickly check that all needed components are at each location. Then, as applicators need a resupply of the primer or topcoating system, they need only to mix all the containers at the next location.

Application of the thin PC overlay system proceeds quite quickly. By proper pre-planning, two men were able to prime and topcoat the power house roof shown in figure 61 in 2 days.

(d) Curing and Protection.—The coated surfaces must be protected until the resin has completely cured to a hard finish. Such condition will normally be obtained within about 30 hours of application of the final topcoat. Low ambient temperatures and/or high relative humidity may lengthen the hardening process.

(e) Safety.—All workers, supervisors, and inspectors involved with the project must be made aware of the procedures required for safe use of the thin polymer concrete coating. The manufacturers of vinyl ester resin and the initiators and promoters provide recommendations for safe storage, handling, and use. These recommendations must be known and followed by users of the materials. The following *minimum* safety requirements must be followed on Reclamation projects:

Storage.—Vinyl ester resin and initiators are heat sensitive and flammable. These materials should be stored away from direct sunlight, in the original shipping containers, in well-ventilated areas away from sources of ignition. The storage temperature should not exceed 80 EF. Storage periods should not exceed manufacturer's recommendations.

Mixing and Handling.—Smoking, flame, or other sources of ignition must not be permitted during mixing and application. Electrical equipment in contact with polymer concrete should be grounded for safe discharge of static electricity. Type B or type ABC fire extinguishers must be provided at the storage, mixing, and application locations. *Never directly mix initiator and promoter, or an extremely violent and explosive reaction will occur*.

Personal Protective Equipment.—Workers using thin polymer concrete overlays must be provided rubber boots and required to use disposable protective clothing. Splash-type

Figure 60.—The thin PC overlay system may be applied with push brooms, squeegees, or heavy industrial grade paint rollers.

Figure 61.—The thin PC overlay system can be applied very quickly. Two workmen completed application to this powerplant roof in 2 days.

safety goggles and impervious gloves must be provided to workers using polymer concrete, and the workers must be required to wear these items. In some instances where ventilation is poor or inadequate, workers may be required to wear organic vapor respirators. The mixing and application site should be provided with portable eyewash equipment capable of sustaining a 15-minute stream of clean, room temperature water.

34. Resin Injection.—Resin injection is used to repair concrete that is cracked or delaminated and to seal cracks in concrete to water leakage. Two basic types of resin and injection techniques are used to repair Reclamation concrete.

(a) Epoxy Resins – Epoxy resins cure to form solids with high strength and relatively high moduli of elasticity. These materials bond readily to concrete and are capable, when properly applied, of restoring the original structural strength to cracked concrete. The high modulus of elasticity causes epoxy resin systems to be unsuitable for rebonding cracked concrete that will undergo subsequent movement. Epoxy resin has been used to seal cracks in concrete to waterflow. The epoxies, however, do not cure very quickly, partic-ularly at low temperatures, and using them to stop large flows of water may not be practical. Cracks to be injected with epoxy resins should be between 0.005 inch and 0.25 inch in width. It is difficult or impossible to inject resin into cracks less than 0.005 inch in width, while it is very difficult to retain injected epoxy resin in cracks greater than 0.25 inch in width, although high viscosity epoxies have been used with some success. Epoxy resins cure to form relatively brittle materials with bond strengths exceeding the shear or tensile strength of the concrete. If these materials are used to rebond cracked concrete that is subsequently exposed to loads exceeding the tensile or shear strength of the concrete, it should be expected that the cracks will recur adjacent to the epoxy bond line. In other words, epoxy resin should not be used to rebond "working" cracks.

Epoxy resins will bond with varying degrees of success to wet concrete, and there are a number of special techniques that have been developed and used to rebond and seal water leaking cracks with epoxy resins. These special techniques and procedures are highly technical and, in most cases, are proprietary in nature. They may have application on Reclamation projects, but only after a thorough analysis has been performed to ensure that the more standard repair procedures will not be successful or cost effective.

(b) Polyurethane Resins.—Polyurethane resins are used to seal and eliminate or reduce water leakage from concrete cracks and joints. They can also be injected into cracks that experience some small degree of movement. Such systems, with the exception of the two-part solid polyurethanes, have relatively low strengths and should not be used to structurally rebond cracked concrete. Cracks to be injected with polyurethane resin should not be less than 0.005 inch in width. No upper limit on crack width has been established for the polyurethane resins at the time this is being written. Polyurethane resins are available with substantial variation in their physical properties. Some of the polyurethanes cure into flexible foams. Other polyurethane systems cure to semiflexible, high density solids that can be used to rebond concrete cracks subject to movement. Most of the foaming polyurethane resins require some form of water to initiate the curing reaction and are, thus, a natural selection for use in repairing concrete exposed to water or in wet environments. At the time this is written, there are no standard specifications for polyurethane resins equivalent to the Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete, ASTM Designation C-881. This current lack of standards, combined with the wide variations possible in polyurethane physical properties, creates the necessity that great care be exercised in selecting these resins for concrete repair. "Cookbook" type application of these resins will not be successful. The Materials Engineering and Research Laboratory (D-8180) of the Denver Technical Services Center is currently testing and evaluating these very useful resin systems. They will provide advice and guidance for field applications if requested.

Because of the high costs (generally about $200.00 per linear foot of injected crack), resin injection is not normally used to repair shallow, drying shrinkage, or pattern cracking.

The *Standard Specifications for Repair of Concrete, M-47* in appendix A contains current materials and procedures specifications for epoxy and polyurethane injection resins.

(a) Preparation.—Cracks, joints, or lift lines to be injected with resin should be cleaned to remove all the contained debris and organic matter possible. Several techniques have been used, with varying degrees of success, for cleaning such cracks. Once injection holes have been drilled, repeated cycles of alternately injecting compressed air followed by water have been very useful in flushing and cleaning cracks subject to water leakage. The successful use of soaps in the flushing water has been reported by some practitioners. Complete removal of such materials once injected into cracks is troublesome and may create more problems than it is worth. The use of acids to flush and clean cracks is not allowed by Reclamation. Cracks subject to epoxy injection for purposes of structural rebonding should not normally be injected with water. The epoxy resins will bond to wet concrete, but they develop higher bond strength when bonding to dry concrete.

(b) Materials.—Epoxy resin used for crack injection should be a 100-percent solids resin meeting the requirements of specification ASTM C-881 for type I or IV, grade 1, class B or C. If the purpose of injection is to restore the concrete to its original design load bearing capabilities, a type IV epoxy should be specified and used. If the purpose does not involve restoration of load bearing capabilities, a type I epoxy is sufficient. No solvents or unreactive diluents should be permitted in the resin.

Polyurethane resin used for crack injection should be a two-part system composed of 100-percent polyurethane resin as one part and water as the second part. The polyurethane resin, when mixed with water, should be capable of forming either a closed cell flexible foam or a cured gel, dependent on the water to resin mixing ratio. However, the resin should be such that, with appropriate water to resin mixing ratios, the resulting cured resin foam can attain at least 20-psi tensile strength with a bond to concrete of at least 20 psi and a minimum elongation at tensile failure of 400 percent. The manufacturer's certification that his product meets these minimum requirements should be required before the injection resins are accepted for use on the job.

(c) Injection Equipment.—Resins can be injected with several types of equipment. Small repair jobs employing epoxy resin can use any system that will successfully deposit the epoxy in the required zones. Such systems could use a prebatch arrangement in which the two components of the epoxy are batched together prior to initiating the injection phase with equipment such as small paint pressure pots. The relatively short pot life of the epoxy makes this technique rather critical as far as timing is concerned.

Large epoxy injection jobs generally require a single-stage injection technique in which the two epoxy components are pumped independently of one another from the reservoir to the mixing nozzle. At the mixing nozzle, located adjacent to the crack being repaired, the two epoxy components are brought together for mixing and injecting. The epoxy used in this injection technique must have a low initial viscosity and a closely controlled set time. Several private companies have proprietary epoxy injection systems (figure 62). These organizations have developed epoxies and techniques which allow them to make satisfactory repairs under the most adverse conditions. One or more of these companies should be contacted regarding any major repairs requiring the epoxy injection technique. Names and addresses of these companies can be obtained from the Materials Engineering and Research Laboratory, Code D-8180, Denver, Colorado.

Polyurethane resins have a very short pot life after mixing and are always prepared and injected with *multiple component*, single stage proprietary equipment similar to that used for large scale epoxy repairs. Reclamation specifications do not permit single component injection of 100-percent pure resin. In every instance, multiple component water-resin mixtures or resin (part A) -resin (part B) mixtures must be used. This equipment mixes the resin system components just prior to the point of crack injection. The size of polyurethane injection equipment varies from small, hand operated, pumps to full size commercial equipment capable of discharging many cubic feet of resin per hour (figures 63 and 64). The pumping pressure required of polyurethane injection equipment may exceed 3,000 psi. There are a number of manufacturers of high quality polyurethane resin injection equipment, and there is seldom any cause to attempt polyurethane injection on a Reclamation project with equipment designed for, or adapted from, other operations. Such adaptation is usually indicative of an inexperienced contractor and is highly discouraged.

(d) Application.—The success of resin injection repair projects is directly related to the experience and knowledge of the injection contractor. Reclamation requires that an injection contractor have a minimum of 3 years' experience in performing injection work similar to that being contracted for and that a minimum of five projects be included in that experience. Reclamation may also accept an injection contractor not having the required experience provided that the work is per-formed under the full-time, direct technical supervision of the injection resin manufacturer, provided the manufacturer has a minimum of 5 years' experience providing resins for applications similar to those specified.

(1) Application of Epoxy Resin by Pressure Injection.—The objective of epoxy resin injection is to completely fill the crack or delamination being injected and retain the resin in the filled voids until cure is complete. The first step in the resin injection process is to thoroughly clean the concrete surface in the vicinity of the cracks of all loose or deteriorated concrete and debris. The area of injection is then inspected and the injection port location pattern established. Several different types of injection patterns can be used:

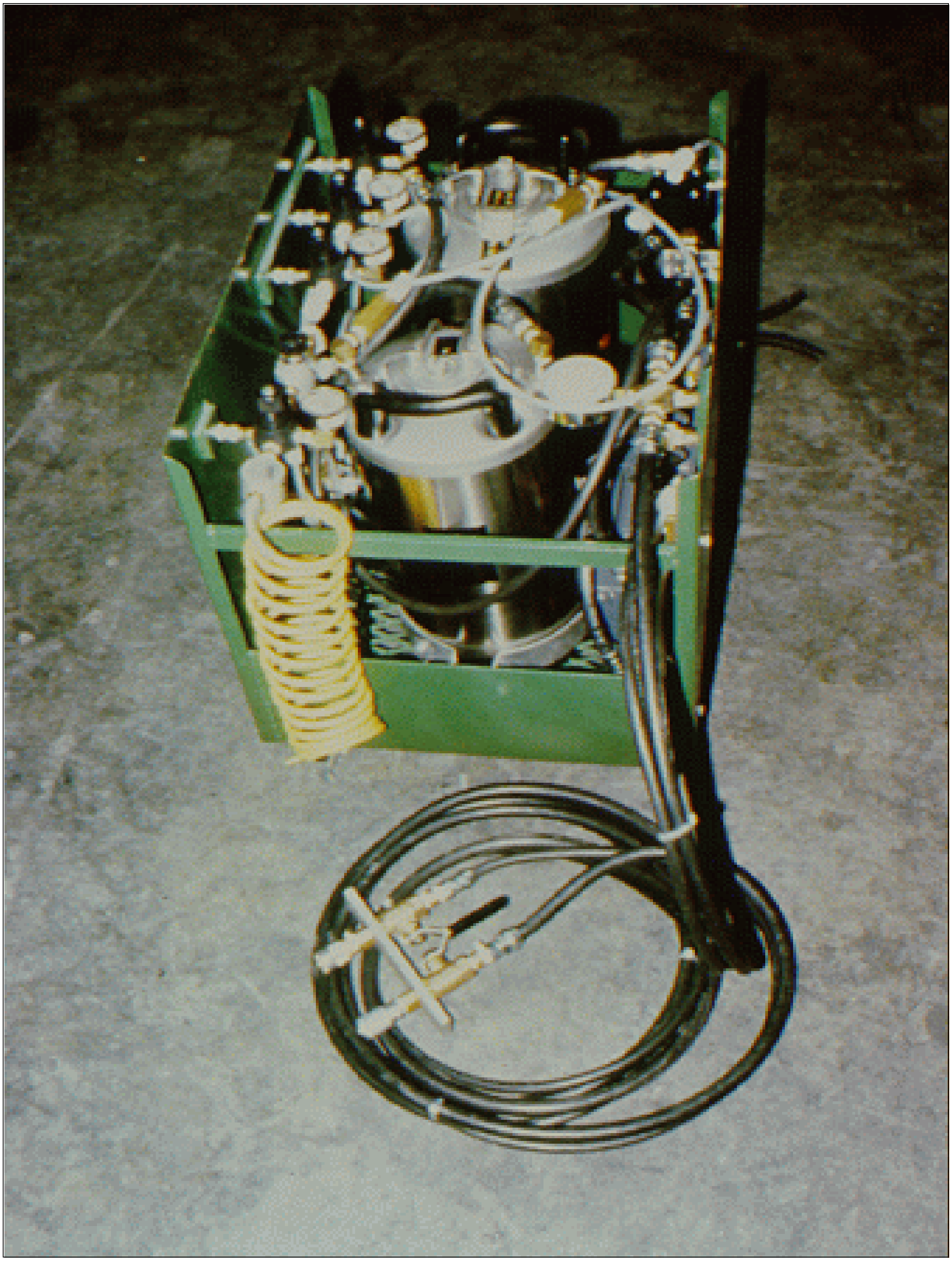

Figure 62.—Proprietary epoxy injection equipment. Such equipment does not mix resin components until the point of injection.

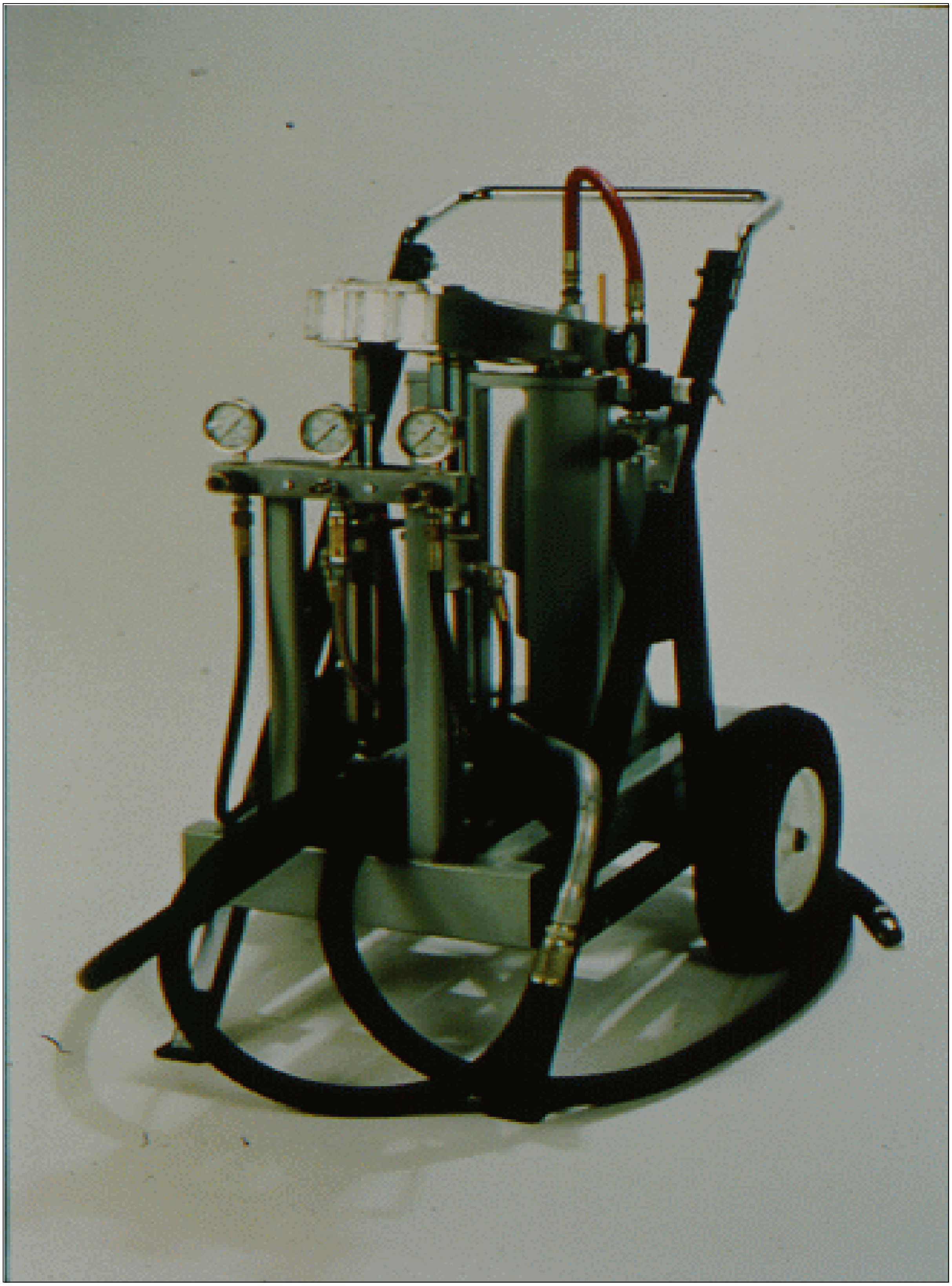

Figure 63.—Commercial polyurethane injection pump.

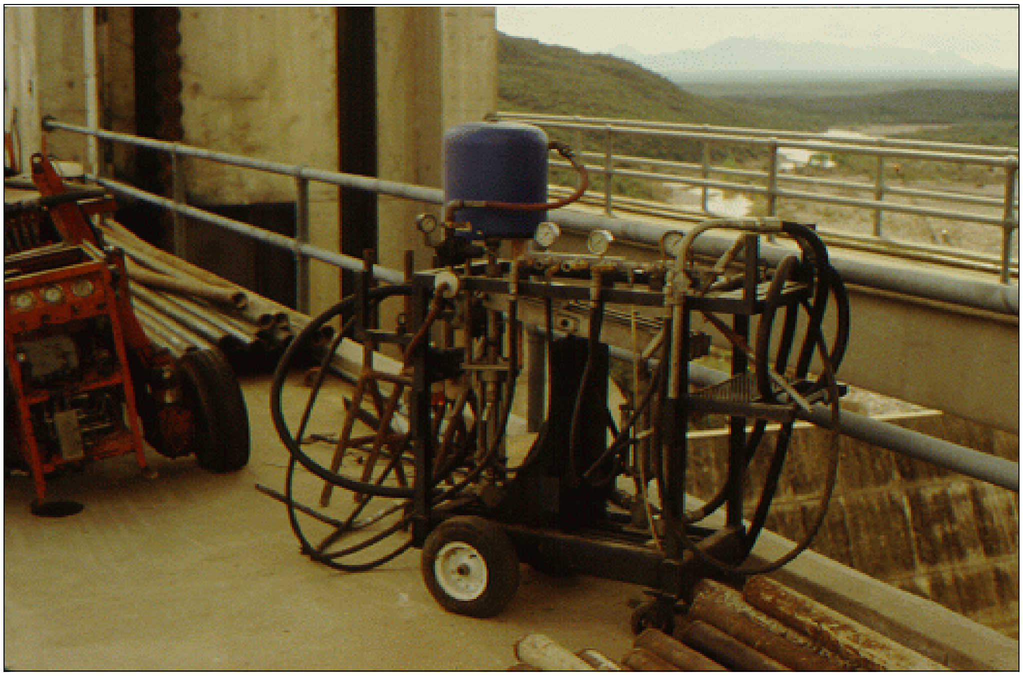

Figure 64.—This is an air-powered pump system used for large scale polyurethane resin injection.

- C If the cracks are clearly visible and relatively open, injection ports can be installed at appropriate intervals by drilling directly into the crack surface. Care should be taken in drilling the ports to prevent drilling debris and dust from blocking or sealing the openings. Special vacuum drill chucks are available for this work. The surface of the crack between ports is then sealed with epoxy paste and the paste is allowed to cure. Epoxy injection begins at the lowest elevation port and proceeds along and up the crack to the uppermost port.

- C A more positive method is to drill holes on alternate sides of the crack, angled to intersect the crack plane at some depth below the surface. This method ensures that the crack will be intersected even if it strikes or dips in unexpected directions. The top surface of the crack is then sealed with epoxy paste, and injection is accomplished as described above.

Low to moderate epoxy injection pressures should be used and patience should be exercised to permit the resin to flow and completely fill the voids existing in the concrete. The use of high injection pressures can result in flow blockage and incomplete filling and, generally, is an indication of an inexperienced contractor.

The best method of ensuring quality epoxy injection work is to require the contractor to prepare and submit for approval his overall, detailed injection plan and then to obtain small diameter proof cores from the injected concrete. If more than 90 percent of the voids in the cores are filled with hardened epoxy, the injection can be considered complete. If injection is not complete, the contractor should be required to reinject the concrete and obtain additional cores at no additional cost to the Government.

(2) Application of Polyurethane Resin by Pressure Injection.—The basic procedure for polyurethane injection consists of first gaining control of the leaking water, followed by pressure injecting resin to seal the cracks. In most instances, the polyurethane injection procedure is almost identical to the processes

followed for cementitious grouting.

To gain control of the waterflow, holes are drilled to intercept the waterflow paths as far as possible from the concrete surface. Valved drains known as "wall spears" (figure 65) are installed in the drilled holes, opened, and used to relieve water pressure in the cracks near the surface. The cracks are then temporarily sealed with wood wedges, lead wool, or resin soaked jute rope to prevent excessive loss of injection resin.

Additional resin injection holes are then drilled on alternate sides of the crack at a maximum spacing of 24 inches. These holes are angled to intercept the crack at a depth of 8 to 24 inches (as concrete thickness allows, these holes should extend as deeply as possible). Injection ports of various design (figure 66) or additional valved wall spears may be installed in the drilled holes, depending on the injection plan and the presence of flowing water.

Polyurethane resin injection should occur according to a preplanned sequence. A system of split spacing similar to cementitious grouting is often successful. In such a system, the primary holes are injected first, followed by drilling and injection of secondary holes located between the primary holes. Similarly, tertiary holes, located between the secondary holes and primary holes are then drilled and injected. Injection pressures should be the minimum pressures necessary to accomplish resin travel and filling. Even so, pressures of 1,500 to 2,000 psi are common in this work. Closure of each injection hole should be accomplished by holding injection pressure for a period of 10 to 15 minutes after injection flow has ceased. This technique of "closure to absolute refusal" ensures that the resin attains maximum density in the crack and becomes a permanent repair. It is usually a mistake to stop injection as soon as the water leakage is stopped. If such a procedure is followed, the partially cured, low density resin can be pushed out of the crack system by hydrostatic pressure, and repeat injection will be required to seal the resulting leakage.

It is also common practice to intermittently inject resin into a port in order to accomplish sealing of large waterflows. With this technique, a preselected quantity of resin is slowly injected into a port, followed by a 15-minute to 2-hour waiting period before repeat injection. Several such cycles of injection may be necessary to control and seal large waterflows. It is still necessary that closure to absolute refusal be accomplished with the final injection cycle.

Polyurethane resin injection is accomplished with varying water to resin ratios. In cases of high waterflows, it may be desirable to inject water to resin ratios as low as 0.5:1. Alternatively, the water and resin may be introduced and mixed in a "residence tube" 1 to 5 feet before the point of injection so the foaming reaction may be well underway upon entering the crack network. Special downhole packers can be utilized to inject resin at points deep within a structure. If resin components are mixed and injected at the surface of such deep holes, the reaction will occur within the drill hole before reaching the desired point of injection into the cracks. These special packers (figure 67) allow separation of the resin components until they reach the downhole point of crack injection.

The necessity of using experienced injection contractors or technical advisors for work of this nature cannot be overemphasized.

(3) Cleanup.—At the completion of resin injection, all injection ports, excess resin, and crack surface sealer should be removed from surfaces that are visible to the public. This can be accomplished by scraping, high pressure water blasting, or grinding. The use of dry pack or other replacement repair material necessary to fill injection holes should be anticipated and provided by the specifications.

35. High Molecular Weight Methacrylic Sealing Compound.—Concrete sealing compounds (see also section 38) are applied to cured, dry concrete as a maintenance procedure to reduce or prevent penetration of water, aggressive

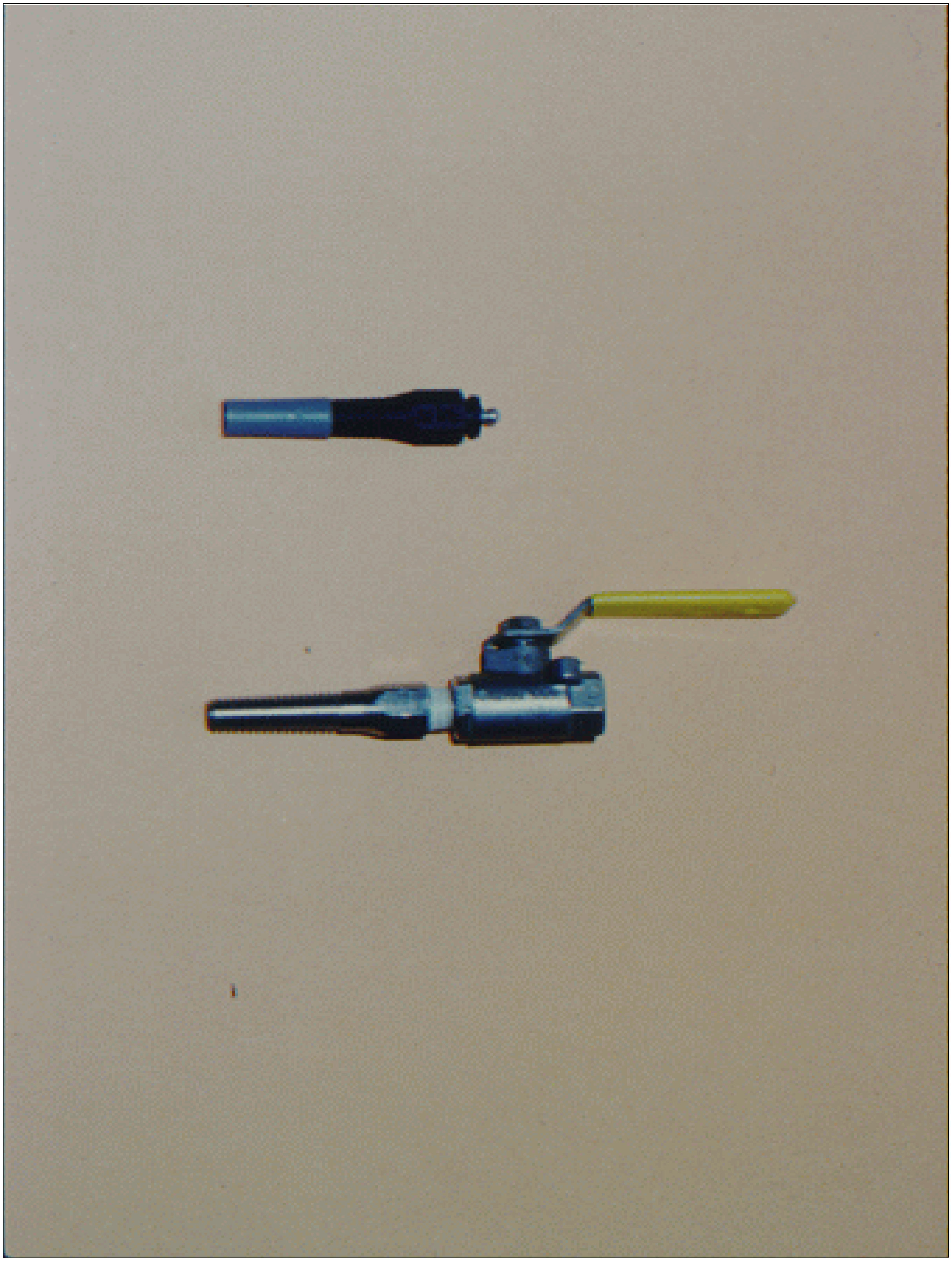

Figure 65.—An injection port with zirc fitting and a valved wall spear are shown in this photograph. The wall spear can be used to relieve water pressure and to inject resin.

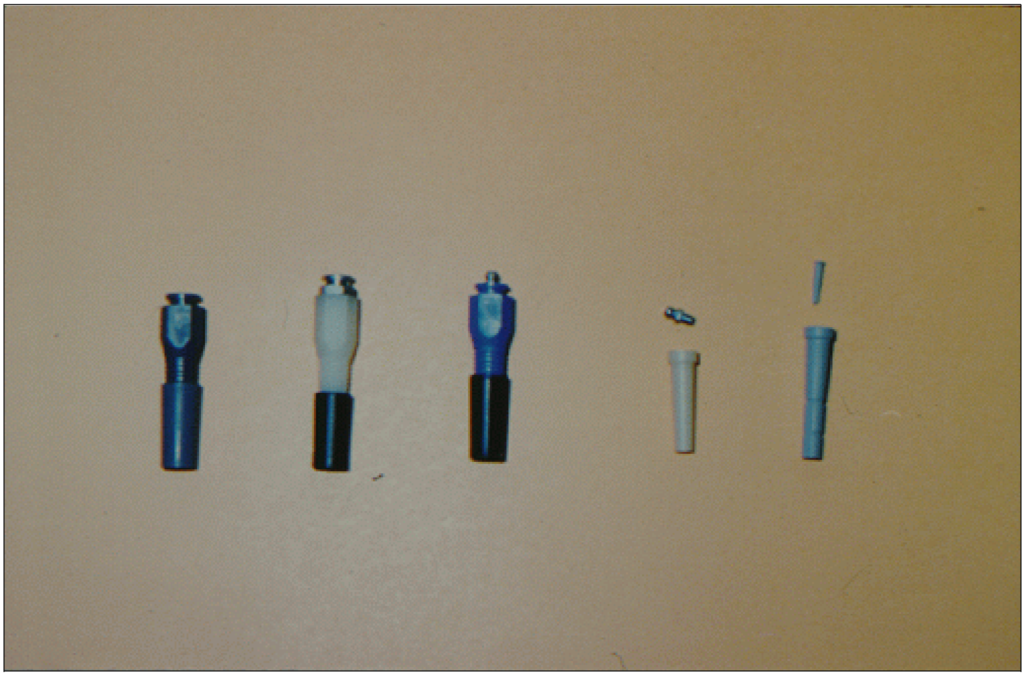

Figure 66.—Several different types of injection ports are shown in this photograph.

solutions, or gaseous media and the associated deterioration, such as freeze-thaw, carbonation, or sulfate damage. These materials replace the linseed oil based treatment, which was generally misunderstood and is no longer recommended for use on Reclamation concrete.

A variety of different membrane forming (similar to paints or coatings) and surface penetrating chemicals are manufactured and sold as sealing compounds for concrete surfaces. Some of these materials provide very good protection to the concrete for discrete periods of time. Other commercially available sealing materials, however, may be little more than mineral spirits and linseed oil. Such systems will, at best, do little harm to the concrete. Their application may, however, prevent subsequent treatment with the sealing compounds that have been proven effective. For this reason, only products that have proven effective in standardized laboratory evaluations should be used on Reclamation concrete. The Materials Engineering and Research Laboratory, D-8180, maintains a current listing of concrete sealing compounds that have been found effective for Reclamation applications.

One type of sealing compound that has proven effective in Reclamation laboratory tests and field applications and has been designated a Standard Repair Material is known as a high molecular weight methacrylic monomer system. This sealing compound is composed of a methacrylic monomer and appropriate polymerization "catalysts" very similar to the monomer system used in polymer concrete (section 32). It is a water thin, amber colored liquid that is easily spread over horizontal and vertical concrete surfaces with brooms or squeegees. The liquid penetrates the concrete surface to a depth of about 1/16 inch *but is most effective in penetrating and sealing cracks in the concrete surface.* This sealer will act like a membrane forming system if excess monomer is applied or if two or more applications are made. The appearance of the concrete following application will be somewhat like a varnished or water wet surface and may be splotchy in areas of high and low absorption. Cured sealer left on the surface of the concrete will be deteriorated by solar radiation within 1 to

Figure 67.—A proprietary downhole packer allows separation of the resin components untilthey reach the downhole point of injection.

2 years and will disappear. The loss of this surface material is of no consequence since the objective of the application is to penetrate and seal cracks where the sealer is protected from solar radiation deterioration. The expected service life of properly applied methacrylic sealing compound under typical Western State climatic conditions is 10 to 15 years. Reapplication is then necessary. Figure 68 shows application of a high molecular weight methacrylic sealing compound to the crest of Kortes Dam.

(a) Preparation.—Concrete to receive methacrylic sealing compound must be dry, clean, and physically sound. The cracks and porosity of wet or damp concrete will be completely or partially filled with water that will prevent the desired penetration of the sealing compound. The concrete is suitably dry if no moisture appears under a sheet of transparent polyethylene taped to the concrete surface during a minimum 2-hour exposure to full sunlight.

Power sweeping or hand brooming followed by blowing with high pressure compressed air should be used to remove all debris from the surface. Very small areas of paint, asphalt, rubber, or similar type coatings can usually be ignored. It should be expected, however, that the methacrylic monomer system will attack and deteriorate most markings or coatings intentionally placed on the concrete. Deteriorated or unsound concrete should be removed following the methods described in section 8. After proper preparation, the concrete must be protected from construction traffic and wetting.

(b) Materials.—The high molecular weight methacrylic sealing compound is usually obtained from the manufacturer as a three-component system:

(1) A water thin liquid methacrylic monomer

(2) Cuemene hydroperoxide initiator (or catalyst)

(3) Cobalt napthenate promoter

Each manufacturer will specify the proper proportions for mixing these materials, and these recommendations must be closely followed. As a general rule, it can be expected that the initiator will be added to the monomer at about 4 to 6 percent, by weight and the promoter at about 1 to 3 percent, by weight. *The initiator and promoter must never be directly mixed with each other, as this will produce an extremely violent and explosive chemical reaction.* Rather, the initiator is first thoroughly mixed with the monomer and then the promoter is added and mixed with the monomer-initiator mixture.

Some manufacturers supply a two-part monomer system already containing the proper proportion of promoter. With such systems, it is necessary to add only the proper quantity of initiator. Once all the components are mixed, the sealing compound system will have a definite and short pot life that cannot be extended under normal conditions.

For this reason, if the project is of sufficient size to require more than 5 gallons of sealing compound, it is usually best to premeasure the required quantity of monomer into separate 5-gallon volumes which are not mixed but are placed at appropriate locations along the application path; each location consists of 5 gallons of monomer, the appropriate quantity of initiator, and the separate and appropriate quantity of promoter (if not already added to the monomer by the manufacturer). During application, as one 5-gallon volume of sealing compound is nearly used up, an additional 5 gallons can then be mixed for use. Since all the 5-gallon materials quantities are premeasured and located along the application path, this system also helps ensure that all necessary components are added and mixed for each volume of sealing compound. Otherwise, it is some-what common to discover that either the initiator or the promoter has been omitted from sealing compound already applied to the concrete, thereby creating a bothersome situation.

(c) Application.—As the mixed monomer system has a distinctly short pot life at normal ambient temperatures, it is important not to mix more material than can be easily applied prior to the system becoming too thick— normally within 15 to 20 minutes. If the material is being applied by two workmen and the application path is clear and easily attained, it would be common to mix up to 5-gallon quantities of material unless the ambient temperatures exceed 85 EF. The sealant should be applied immediately after mixing. Application of the sealant system to concrete in direct sunlight should be avoided. Solar radiation greatly shortens the working pot life of the mixed sealant. Workmen can use squeegees, industrial size paint rollers, push brooms, brushes, or airless powered spray systems to apply the sealant system. What is desired is to flood the concrete with a heavy uniform coverage without leaving puddles of excess material. Application rates will normally vary from 75 to 100 square feet per gallon, depending on surface roughness and absorption. Vertical surfaces should receive two or more brushed, sprayed, or rolled applications. Repeat applications should be made immediately, without waiting for the sealant to cure.

If a skid-resistant surface is required for foot or vehicle traffic, sand must be broadcast over the liquid sealant system within 15 to 20 min-utes of application. The sand gradation is contained in the appendix A specifications. The sand application rate should be about 1/4 to 1/2 pound per square yard of surface

(d) Curing and Protection.—After application, the treated surfaces should be protected for a minimum of 24 hours. Protection should be provided for 48 to 72 hours if ambient temperatures are lower than 50 EF to permit the sealant to fully cure. Sealant applied during the night will be quickly cured by solar radiation the following morning. Night applications allow the maximum penetration into cracked surfaces and should be pursued whenever practicable.

(e) Safety.—The safety provisions of section 33.(e) should be followed when using high molecular weight methacrylic sealants. Storage of initiator and promoter in the same room is prohibited. Storage of initiator under refrigerated conditions is desirable. Every precaution should be taken to prevent mixing or direct contact of initiator and promoter.

36. Polymer Surface Impregnation.—The polymer surface impregnation process was developed by Reclamation for the Federal Highway Administration to prevent chloride deicing salt penetration and subsequent corrosion of reinforcing steel in existing concrete highway bridge decks. The process has provided in excess of 20 years of highly successful protection to many highway bridge decks and was applied to the entire roadway surface over Reclamation's Grand Coulee Dam.

In this process, the concrete to be treated is first covered with a bed of sand and dried with heat to remove moisture from the zone to be impregnated. A low viscosity methyl methacrylic monomer system is applied to the sandbed under a heavy polyethylene sheet and allowed to soak into the concrete surface for about 6 hours. The polyethylene retards evaporation of the highly volatile monomer system, and the sand acts as a reservoir, retaining the monomer system on the concrete until it soaks into the surface. The polyethylene covered sand and treated surface is then reheated to initiate in-situ polymerization of the methyl methacrylate monomer system within the structure of the concrete. Concrete so treated will be virtually impervious to water absorption and freeze-thaw deterioration.

Detailed materials and performance specifications for the polymer surface impregnation process are contained in section 3.13 of appendix A. Users considering application of this procedure should carefully appraise the current costs and associated safety issues. The costs of energy to properly dry and reheat areas of concrete may preclude large scale use of this very effective preventative maintenance process.

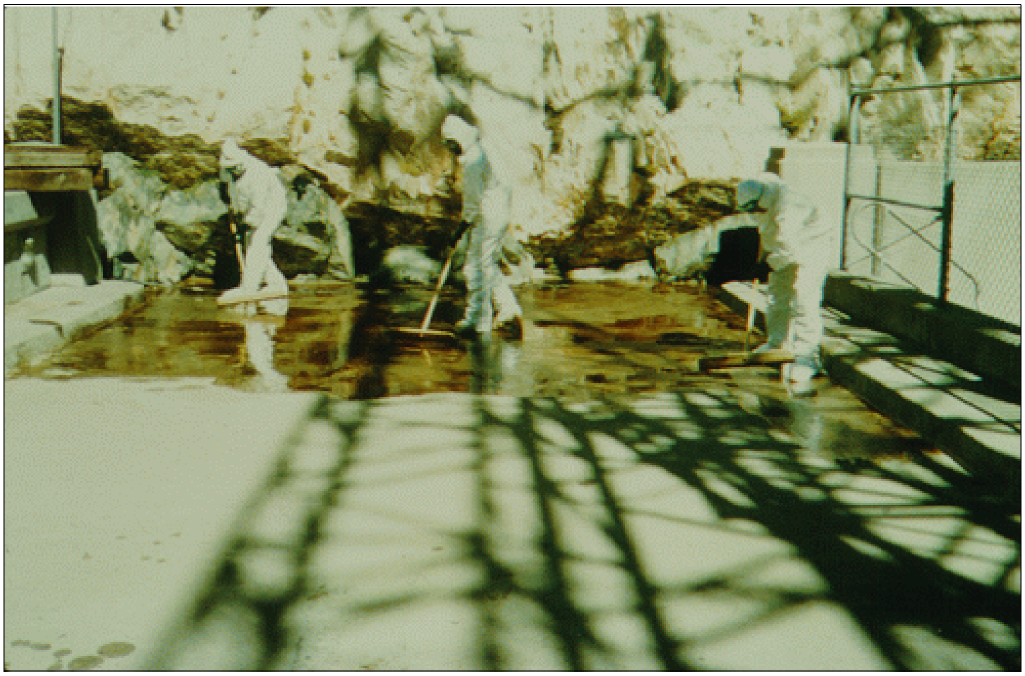

Figure 68.—High molecular weight methacrylic sealing compound is being applied tothe crest of Kortes Dam, near Casper, Wyoming.

37. Silica Fume Concrete.—Silica fume concrete is conventional portland cement concrete containing admixtures of silica fume. Silica fume is a finely divided powder by-product resulting from the use of electric arc furnaces. When mixed with portland cement concrete, silica fume acts as a "super pozzolan." Concrete containing 5 to 15 per-cent silica fume by mass of cement commonly can develop 10,000- to 15,000-psi compressive strengths, reduced tendency to segregate, very low permeabilities, and enhanced freeze-thaw and abrasion-erosion resistance. Reclamation use of silica fume is primarily for the purpose of enhancing or improving concrete durability with less emphasis on strength improvement.

Silica fume concrete is the repair material of choice for applications requiring enhanced abrasion-erosion resistance and/or reduced permeability. Silica fume concrete requires a very thorough curing procedure, however, and should not be used unless such a procedure can be accomplished. Otherwise, this repair material is used in accordance with the provisions for conventional replacement concrete.

The silica fume admixture can be obtained in at least three forms for use in concrete:

(1) Silica fume powder

(2) Densified silica fume powder with or without a high range water reducing admixture (HRWRA) and other dry admixtures

(3) Silica fume-water slurry with HRWRA and other admixtures

The dry silica fume powder is difficult to use because of its extremely small particle size. The fine powder drifts and spreads in any draft or air movement and can create silicate respiratory problems to workers. The water slurry form is easy to use, creates no dust problems, but does involve an additional mixing step as the slurry settles during storage and shipment and must be stirred and remixed prior to use. The water in the slurry must be accounted during mix design. Transportation costs of the slurry must also be considered. The densified powder form is currently the most convenient form to ship and use. In this form, the silica fume powder is compacted and densified and does not produce nearly the quantity of dust that occurs with the powdered form. It is a dry material and does not create additional shipping costs. Because it has been compacted into clumps, it should be expected that additional time would be required during mixing to fully break up and disperse the densified silica fume admixture in the concrete mixture.

Because of these various forms, it is essential that trial mixtures be prepared and tested during mix design to ensure development of the desired concrete properties.

The addition of silica fume admixture to concrete will increase the water requirement due to the high surface area of the very fine silica fume particles. The use of HRWRA is thus necessary to obtain the maximum strength and durability with silica fume concrete. Provisions should be made during proportioning, however, to accommodate the slump gain commonly associated with concrete containing HRWRA. Silica fume increases the cohesion or "stickiness" of the concrete and can result in workability and finishing problems for those inexperienced in the proper finishing techniques. It is of primary importance to place and finish silica fume quickly, before excessive mix water evaporation and stiffening occurs. The slump gain from the HRWRA commonly offsets some of the "stickiness" of silica fume concretes. Reclamation requirements include 4-6 percent entrained air in silica fume concrete. This addition of air entraining admixture also improves the workability of the concrete.

Special repair techniques are required for restoration of damaged or eroded surfaces of spillway or outlet works tunnel inverts and stilling basins. In addition to the usual forces of deterioration, such repairs often must withstand enormous dynamic and abrasive forces from fast-flowing water and sometimes from suspended solids. The enhanced abrasion-erosion resistance and high strength of silica fume concrete makes it the repair material of choice for these types of repair. It should be recognized, however, that the cause(s) of the original damage in such repairs must be mitigated if a permanent repair is to be accomplished.

Whenever practicable, low slump silica fume concrete should be used for these types of repair. Slump of the concrete should not exceed 2 inches for slabs that are horizontal or nearly horizontal and 3 inches for all other concrete. (This is 1 inch less slump than required in the M-47 specifications for conventional applications of silica fume concrete.) The net water-cementitious ratio (exclusive of water absorbed by the aggregates) should not exceed 0.35, by weight. An air-entraining agent should be used, and a high range water reducing admixture should be used. Set-retarding admixtures should be used only when the interval between mixing and placing is quite long.

(a) Preparation.—Concrete to be repaired with silica fume concrete should be prepared in accordance with the requirements of section 8.

(b) Materials.—There are currently no ASTM specifications for the silica fume admixture. Reclamation has been approving silica fume meeting the requirements of the Standard Specification for Microsilica for Use in Concrete and Mortar, AASHTO Designation: M 307-90.

All other materials, including the requirement for 4- to 6-percent entrained air, should be in accordance with the provisions of section 29.

(c) Application.—Silica fume concrete must be mixed, transported, and placed in accordance with the highest quality procedures for conventional concrete technology and with the provisions of section 29.

The following silica fume concrete mix design is included as a reference or starting point only. Proper proportioning of silica fume concrete requires trial mixes:

Material	
Portland cement	679.3 lb/yd^3
Coarse aggregate (3/4-in. MSA)	1,910.9 lb/yd^3
Sand	1,036.2 lb/yd^3
Water	169.0 lb/yd^3
Silica fume slurry[1] = 13.3 percent by mass of cement	200.6 lb/yd^3
Total	3,996.0 lb/yd^3
HRWRA	300 cc

$$\text{w/c ratio} = \frac{\text{Water} + 0.51(\text{slurry}) = 239.2}{\text{Cement} + 0.45(\text{slurry}) = 769.5} = 0.35$$

[1] Silica fume slurry contains 51 percent water, 45 percent cementitious silica fume, and 4 percent admixtures, all by mass. The admixtures consist of HRWRA and air entraining admixture. In this instance, additional HRWRA was required to produce a workable concrete.

Silica fume concrete is placed and finished using conventional equipment and procedures. As previously discussed, placement should be done quickly to allow finishing before stiffening occurs. Consolidation and compaction should be accomplished with internal vibrators. Vibrating screeds can be used for larger placements and, usually, a single pass of multirow screeds will provide an adequate surface finish. Small repair areas can be hand screeded (figure 69). Bull floats can be used after screeding, but floating must be done immediately after screed passage (figure 70). Hand troweling silica fume concrete is usually not too effective, except for small repairs, because it takes too long. There is very little bleed water development after placing silica fume concrete. This can result in plastic and drying shrinkage cracking under conditions of elevated temperatures, low humidity, and high wind conditions which cause rapid water evaporation from the concrete surface (see section (d) below). The use of a long chain cetyl alcohol evaporation retarding finishing aid is highly recommended under such conditions.

(d) Curing.—Silica fume concrete must be properly cured if a successful repair is to result. Fresh silica fume concrete has very low or no bleed water development. This is due to the affinity silica fume has for water and to the low water-cement ratio of the mix. If the rate of evaporative water loss from the surface of freshly placed silica fume concrete exceeds the rate of bleed water development, plastic shrinkage cracking of the surface will result. Evaporative water loss must be prevented by such measures as immediate application of curing compound, covering the fresh concrete with plastic membrane, water fogging or flooding, use of an evaporation retarding finishing admixture, and by immediate curing. The common practice (with conventional concrete) of allowing the development and evaporation of bleed water from the surface prior to beginning curing will always result in cracking of silica fume concrete. It is best to begin the curing of silica fume concrete immediately after finishing. Very successful curing of stilling basin repairs has resulted from flooding the repair area with water immediately after the silica fume concrete has attained initial set. Even so, water evaporation from the concrete surface must be prevented prior to flooding. The spillway repairs shown in figures 69 and 70 were cured by applying curing compound and covering with polyethylene immediately after floating, even while placing operations were continuing (figure 71). Water trickler hoses were placed under the polyethylene as soon as the concrete attained initial set, and water was applied continuously for 14 days. This thin, 4- to 6-inch deep, repair has experienced virtually no shrinkage cracking.

(e) Safety The same safety provisions should be followed as with the use of any portland cement product, except that additional precautions must be taken to prevent inhalation of silica fume dust. The high silica content of silica fume dust can lead to development of silicosis if proper respirators are not used by workmen participating in or downwind of mixing operations.

38. Alkyl-Alkoxy Siloxane Sealing Compound This sealing compound is effective in reducing water penetration into treated concrete, provided that the sealing compound contains in excess of 15-percent siloxane solids. These solids are suspended in a carrier such as alcohol or mineral spirits that evaporates from the concrete following application. Use of this type of sealing compound does not cause a

Figure 69.—This workman is hand screeding a small silica fume concrete repair.

Figure 70.—Using a bull float on a silica fume repair. Finishing must be done immediately after screeding.

Figure 71.—Curing compound and polyethylene sheeting should be applied to cure silica fumeconcrete as soon as finishing is completed if drying shrinkage cracking is to be prevented.

change in the appearance of the treated concrete, except that the darkening normally associated with water wetting of concrete does not occur. It is common to see water bead on treated concrete surfaces. Siloxane sealing compounds will not provide protection to concrete that is completely inundated in water except for short periods. They should not be used under conditions that involve prolonged inundation such as occurs with stilling basins, canal floors, or spillway floors unless there are significantly long dry periods between inundations and it is acceptable to reapply the sealing compound following inundation. Siloxane sealing compound is best used to protect concrete from rain, snowmelt, and water splash zones.

These materials have a relatively limited service life, and reapplication should be scheduled about every 5 to 7 years for optimum protection. Application of these materials, however, proceeds very quickly on horizontal and vertical concrete surfaces. Two workmen can be expected to treat 10,000 to 15,000 square feet of horizontal surface in a day. Cost of siloxane sealing compound and application average about $0.50 to $0.70 per square foot.

(a) Preparation.—Concrete surfaces to be treated with siloxane sealing compound should be dry, clean, and sound. All deteriorated concrete should be removed (section 8), and all needed repairs should be accomplished prior to application. As a general rule, power sweeping and, in some instances, high pressure (less than 8,000 psi) water washing of the surfaces will be suf-ficient. The concrete should be allowed to dry for 24 to 48 hours following wetting. Cracks in the concrete should be cleaned and blown out with compressed air to remove any debris. Once preparation (including drying if needed) is completed, the sealing compound should be applied within 24 hours.

(b) Materials.—Siloxane sealing compound should be a one-part, ready to apply, oligo-meric alkyl-alkoxy siloxane containing no less than 20 percent active solids, by mass, in a clear organic carrier. Siloxane sealing compounds

Figure 72.—A paint roller application of siloxane sealing compound to the downstream face of Nambe Falls Dam, near Santa Fe, New Mexico.

containing less than 20 percent active solids do not provide sufficient protection to the concrete and are not allowed by section 3.15.d of the M-47 specifications in appendix A. The material should be supplied in 5-gallon pails or 55-gallon drums. No additional mixing or blending should be necessary prior to application. No additional solvents or diluents should be added to the supplied sealing compound.

(c) Application.—The sealing compound should be applied to the concrete using squeegees, push brooms, paint rollers (figure 72) or low pressure airless spray equipment. Adjacent glass, metal, and painted surfaces must be protected from the sealing compound. Overspray protection must be provided if spray application equipment is utilized. Fine spray mists can travel extensively and damage downwind structures, equipment, and automobiles.

The application rate should be 1 gallon per 80 to 120 square feet of concrete surface. Horizontal and vertical surfaces should receive two wet to wet coatings, 5 or so minutes apart, flooding the surface each time. Excess sealant should be broomed out until it is absorbed by the concrete. Low density areas of the concrete surface need the most protection, and these areas are the most absorptive.

(d) Curing.—Siloxane treated concrete must be protected from foot and vehicular traffic and water wetting for 24 hours following application. Should the concrete experience rain or heavy water splashing during this period, the drying step of preparation should be repeated and reapplication made.

(e) Safety.—Siloxane sealing compounds are formulated with organic solvents such as alcohol or mineral spirits. Materials Safety Data Sheets should be consulted concerning flammability and toxicity. Applicators should wear protective coveralls, rubber boots, eye protection, and approved respirators.

Chapter V

Nonstandard Methods of Repair

39. Use of Nonstandard Repair Methods.— The standard concrete repair methods/ materials discussed in chapter IV will meet nearly all concrete repair needs. There will be occasions, however, resulting from unusual causes of damage and exposure conditions or special repair needs, when the standard repair methods may not meet the performance needs. In these infrequent instances, non-standard repair methods may be required.

Repair materials are considered to be non-standard if they have not been thoroughly tested and evaluated for Reclamation applications. The use of such materials involves a certain element of risk because the performance properties of these materials are unknown or not fully defined. The application of nonstandard materials can be justified only when it has been determined that no standard repair material will serve, and if all parties associated with or responsible for accomplishing the repairs are made to understand the risks and agree to accept the uncertainties and possible consequences.

An example of such a situation would be the need to repair concrete damage on the crest of a dam that is less than 1-1/2 inches deep. There is no standard repair material suitable for such shallow repairs when exposed to sunlight temperature variation conditions. (These conditions eliminate the use of epoxy mortars.) The current standard repair material for depths between 1-1/2 inches and 6 inches is epoxy-bonded replacement concrete. If the deterioration is not at least 1-1/2 inches deep, sufficient concrete must be removed to accomplish a 1-1/2- inch depth. If, for some reason, it was undesirable or impossible to remove the required depth of concrete, it might be appropriate to select one of the proprietary thin repair products. These materials have been only partially evaluated (Smoak and Husbands, 1996) and the long- term field performance has not yet been fully determined. In this example, the people responsible for the dam must be contacted, and the risks of using an unproven repair material must be made known to them. These responsible personnel, with this knowledge, can then determine if the benefits of performing the shallower repairs would outweigh the uncertainties associated with unproven performance.

(a) Preparation.—Concrete preparation for repair with nonstandard materials should be in accordance with section 8 unless required otherwise by the materials manufacturer. The recommendations of the manufacturer should be closely followed.

(b) Materials.—Nonstandard repair materials will be proprietary or commercial products in most instances. Manufacturer's technical representatives should be contacted and made fully aware of the nature of the problem and the causes for selecting nonstandard repair materials. They must be informed of any secondary considerations, such as the need to accomplish repairs on an emergency basis or the inability of taking the structure to be repaired out of service except at certain times. Copies of materials warranties should be obtained if available. Technical representatives should be questioned closely about the conditions under which their materials *would not be suitable* for use or when the materials *warranties would not apply*. The manufacturer should be able to supply case studies or project histories of use of their materials to repair similar damage.

(c) Application.—Application of nonstandard repair materials must be made in exact conformance to the manufacturer's recommendations. Failure to apply the materials properly will void any warranties and is a commonly cited reason for proprietary material failure. Construction inspection reports should closely note any contractor variance from the manufacturer's recommended application procedures.

(d) Curing.—Curing of nonstandard repair materials must be performed exactly as recommended by the materials manufacturer.

(e) Safety.—Nonstandard repair materials could contain compounds not commonly encountered during repair construction. Copies of the Materials Safety Data Sheets must accompany the shipment of materials to the jobsite. They should be consulted and appropriate safety provisions developed.

Appendix A

Standard Specifications for the Repair of Concrete
M-47, 08-96

M-47

(M0470000.896)

STANDARD SPECIFICATIONS

FOR

REPAIR OF CONCRETE

August 1996

United States
Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver Federal Center
Denver, Colorado 80225-0007

Contents

HOW TO USE THIS MANUAL

This manual is divided into 3 sections. The general requirements contained in section 1 and the concrete preparation requirements contained in section 2 always apply to each and every Reclamation concrete repair project. Section 3 consists of a number of paragraphs containing the special requirements of the various repair materials and techniques. Once a repair material/technique has been properly selected from section 3 (see "Step 4. Choose An Appropriate System" below) it should be sufficient in preparing a job specific specification to simply require that the repairs be performed in accordance with the provisions of section 1, section 2, and section 3.X of this manual.
Assistance in using this manual or with any other phase of concrete repair of Reclamation structures can be obtained by contacting:

Glenn Smoak or Kurt von Fay
Materials Engineering and Research Laboratory
Code D-8180
Technical Service Center
P.O. Box 25007
Denver, Co 80225
phone 303-236-3730.

The standard concrete repair materials and techniques described in this manual have been developed and evaluated by the Bureau of Reclamation over a period of some 90 years. Unfortunately, during this time many repair failures have occurred on Reclamation concrete structures even though very durable repair materials were specified and used. In evaluating the causes of these failures it has been learned that it is essential to consistently use a systematic approach to repairing concrete. Many such such repair systems exist and this manual will not attempt to discuss or evaluate which of these systems is best for any set of field conditions. Rather, the following repair system has been used by Reclamation over a long period of time and has been found to result in successful concrete repairs. This system, known as "The Seven Steps of Concrete Repair", is suitable for repairing both construction defects in new concrete as well as old concrete damaged by long exposure to field conditions. In using this system it is necessary to take the steps in numerical order. Quite often the first questions asked when damaged concrete is detected is "What should be used to repair this?" or "How much will the repair cost?". These are not wrong questions. Rather they are asked at the wrong time. With a systematic approach these questions are asked only when sufficient information is available to provide correct answers.

The Seven Steps of Concrete Repair

1. Determine the cause of damage
2. Evaluate the extent of damage
3. Determine the need to repair
4. Choose an appropriate repair system
5. Prepare the old concrete
6. Apply the repair system

7. Cure the repair properly

Step 1. Determine the cause of damage - It is essential to correctly determine the causes(s) of the damage to the concrete. If this is not done, or if the determination is incorrect, the cause of damage will most likely attack and deteriorate the repair. The money spent for such repairs is, thus, totally lost and larger replacement repairs become necessary at much higher cost.

Step 2. Evaluate the extent of damage - The objective of this step is to determine how much of the structure is damaged and how extensive the damage is.

Step 3. Determine the need to repair - Not all damage to concrete requires repair. Repairs should be undertaken only if they will result in longer or more economical service life, a safer structure, or necessary cosmetic improvements in the structure. This step also includes determination of when the structure can be taken out of service for repairs, an estimate of how long the repairs will take, and how to budget the costs of the repairs.

These first 3 steps are the major components of a condition survey. Only after they have properly been performed should one proceed with selecting and installing the repair materials.

Step 4. Choose an appropriate repair system - Upon completion of the first 3 steps, an appropriate repair system can be selected that takes into consideration the many factors essential to a successful repair. In a majority of the repair situations, the standard materials and methods in this specification will fully meet all repair needs. It should be recognized, however, that service conditions or special repair situations will occur where these "standard materials" will not meet the special requirements and it will be necessary to resort to "non-standard" repair materials or methods. Such materials are continually being tested and evaluated by Reclamation laboratory and field offices. They include materials that may have performed quite well in laboratory tests but have not yet been applied in the field, materials not yet having long or sufficient field service to determine service life expectancy, or newly developed commercial materials not yet tested or evaluated by Reclamation. It is appropriate to use such repair materials and techniques only when it has been determined that none of the standard repair materials will properly serve, and when it is fully understood and agreed by all involved parties that the risks associated with the use of unproven materials are justified by the expected benefits of repair success and are acceptable.

Step 5. Prepare the old concrete - The most common cause of repair failure is improper or inadequate preparation of the old concrete prior to application of the repair material. Even the best of repair materials will give poor service life if bonded to weakened or deteriorated old concrete. The provisions of section 2 of this manual provide only the minimum preparation requirements. It should be noted that each of the standard repair materials has special preparation requirements and that these requirements are listed under paragraphs f of section 3. That is, for example, the special preparation requirements for replacement concrete will be listed under paragraphs 3.6.f while those of epoxy bonded concrete will be listed under paragraphs 3.8.f.

Step 6. Apply the repair system - Each standard and non-standard repair material has application procedures specific for that material. For example, the procedures used with replacement concrete are vastly different from those necessary for polymer concrete or epoxy bonded concrete. It is essential that proper application techniques as listed in the section 3 paragraphs g for each material be followed exactly.

Step 7. Cure the repair properly - The second most common cause of repair failures is improper or inadequate curing. Each repair material has specific curing requirements. As an example, replacement concrete benefits from long periods of water curing while latex modified concrete, currently a non-standard material, requires 24 hours water curing followed by drying to allow formation of the latex film. Polymer concrete has essentially no curing requirements while those of silica fume concrete are are exceedingly exact. Failure to achieve proper cure for the proper duration, as listed in section 3 paragraphs f, will result in loss of the repair at the final step of the process.

SECTION 1 - GENERAL REQUIREMENTS

1.1 GENERAL

Concrete that is damaged from any cause; structural concrete that has cracked; concrete that is honeycombed, fractured, or otherwise defective; and concrete that, because of excessive surface depressions, must be excavated and built up to bring the surfaces to the prescribed lines, shall be repaired or replaced in accordance with these specifications and contract requirements.

The method of repair or replacement (procedure) shall be as determined and directed by the Contracting Officer.

Contract, as used herein, shall mean the contract which, by reference, these specifications are included in and made a part. Contracting Officer, as used herein, shall mean the person executing the contract on behalf of the Government, and shall include duly authorized representatives. Contractor, as used herein, shall mean the party entering into the contract with the Government, and shall include subcontractors, suppliers, manufacturers, and agents at all tiers.

1.2 DESIGNS

Concrete mixture proportions, compressive strengths, and other design requirements shall be as specified in these specifications. Designs by the Contractor shall be subject to the approval of the Contracting Officer.

1.3 SUBMITTALS

Submittals shall be in accordance with these specifications and the contract requirements entitled "Submittal Requirements." The Contractor shall submit MSDS (Material Safety Data Sheets), approval drawings and data, repair plans, certifications, material samples, test data and samples, and other submittals as required in these specifications. The Contractor shall be responsible for the accuracy of all submittals.

Unless specified otherwise submittals shall include the original and 2 copies.

1.4 QUALITY ASSURANCE

Quality assurance shall be in accordance with the requirements of the contract entitled "Quality Assurance," and with the requirements of these specifications.

All concrete shall be repaired as necessary to produce surfaces conforming to the specified tolerances and finish requirements of the contract in which these specifications are incorporated by reference and as outlined in section 3.

If, in the opinion of the Contracting Officer, the results of concrete repair indicate that proper quality control procedures are not being consistently utilized, further repair work may be suspended in whole or in part at the discretion of the Contracting Officer. Such suspension will be effective until the Contractor demonstrates substantial improvement in quality control procedures and repair results.

a. Contractor's quality control. - In accordance with the clause in the contract entitled "Inspection of Construction," the Contractor shall be responsible for providing quality control measures to ensure compliance of the repair with these specifications. The Contractor shall implement necessary and appropriate quality control procedures to ensure that all concrete repairs conform to the requirements of these specifications.

b. Government inspection and tests. - Government inspection and tests will be in accordance with the clause in the contract entitled "Inspection of Construction," and with these specifications.

Not less than 24 hours in advance of any concrete repair, the Contractor shall inform the Contracting Officer when the concrete repairs will be performed and, unless inspection is specifically waived, the repairs shall be performed only in the presence of an authorized representative of the Contracting Officer.

c. Testing. - Except as specified in paragraphs 3.5 and 3.12 of the specifications the Contractor shall perform all tests. The Contractor shall provide all materials, equipment, and labor necessary for performing the tests at no additional cost to the Government.

d. Approval. - Approval of the repairs will be based on the inspection and testing requirements of these specifications.

e. Rejection. - Repairs that fail to meet the requirements of these specifications will be rejected.

1.5 MATERIALS AND WORKMANSHIP

a. Materials. - The Contractor shall furnish all materials for repair or maintenance of concrete and shall furnish all materials for forming, curing, and protection of the repairs, as required. All materials shall meet materials specifications as specified in section 3, and all equipment used and methods of operation for the repair or maintenance of concrete shall be subject to approval of the Contracting Officer.

The references to materials in the specifications, wherein manufacturer's products or brands are specified by "brand name or equal" purchase descriptions, are made as standards of comparison only as to type, design, character, or quality of the article required, and do not restrict the Contractor to the manufacturer's products or to the specific brands named. It shall be the responsibility of the Contractor to prove equality of materials and products to those referenced and to provide all descriptive information, test results, and other evidence as may be necessary to prove the equality of materials or products which the Contractor offers as being equal to those referenced.

b. Workmanship. - Concrete shall be repaired by skilled workmen as outlined in section 3.

1.6 SAFETY

All work shall be performed in accordance with the applicable safety and health standards, the requirements of Reclamation's "Health and Safety Standards," the contract, and these specifications. Certain additional safety precautions shall be employed to prevent skin and eye contact with chemicals, resins, or monomeric materials. Protective glasses and clothing, including rubber or plastic gloves shall be worn by all persons handling monomeric materials. All exposed skin areas shall be protected with a protective barrier cream formulated for that purpose. Barrier cream for skin protection shall be specified for the materials used and approved by a physician. Adequate ventilation shall be provided and maintained at all times during use of monomeric materials and solvents. Fans used for ventilating shall be explosion proof. If necessary, respirators that filter organic fumes and mists shall be worn. All contaminated materials such as wipes, empty containers, and waste material shall be continually deposited in containers that are protected from spillage. Spillage shall be immediately and thoroughly cleaned up and disposed of in accordance with applicable regulations.

Federal Standard No. 313, as amended, for the preparation and submission of material safety data sheets is hereby incorporated and made a part of these specifications.

In accordance with the clause in the contract entitled "Hazardous Material Identification and Material Safety Data," the Contractor shall submit a completed MSDS (Material Safety Data Sheet), Department of Labor Form OSHA-174, or GSA-approved Alternate Form A for each hazardous material as required by Federal Standard No. 313, as amended. The information in this MSDS shall be followed to assure safe use, handling, storage, and an environmentally acceptable disposal of the commodity used on the job site.

The Contractor shall submit to the Contracting Officer, not less than 30 days prior to job site delivery of each hazardous material, completed MSDS and identification and certification for the material.

1.7 REPAIR PROCEDURES

All repair or maintenance procedures shall be performed in accordance with the applicable specifications of section 3, including surface preparation, forming, finishing, and curing.

SECTION 2 - CONCRETE PREPARATION FOR REPAIR

Concrete to be repaired shall be prepared in accordance with the requirements of this paragraph and with the special requirements of section 3.

2.1 REMOVAL AND CLEANING

All damaged, deteriorated, loosened, or unbonded portions of existing concrete shall first be removed by water blasting, bush hammering, jack hammering, or any other approved method, with approved equipment, after which the surfaces of existing concrete shall be prepared by contained shotblasting, wet sandblasting, or water blasting to remove any microfractured surfaces resulting from the initial removal process. The surfaces shall then be cleaned and allowed to dry thoroughly, unless the specific repair technique requires application of materials to a saturated surface. Concrete removal processes involving the use of jack hammers in excess of 30 pounds, dry sandblasting, or scrabblers shall not be used without approval by the Contracting Officer. The use of acids for cleaning or preparing concrete surfaces for repair will not be permitted.

2.2 SAW CUT EDGES

The perimeters of repairs to concrete that involve concrete removal and subsequent materials replacement shall be saw cut perpendicular to the repair surface to a minimum depth of 1 inch. Featheredge repairs to concrete shall not be used.

2.3 REINFORCING STEEL

All loose scale, rust, corrosion by products, or concrete shall be removed from exposed reinforcing steel. Reinforcing steel exposed for more than one-third of its perimeter circumference shall be completely exposed to provide 1-inch minimum clearance between the steel and the concrete. Damaged or deteriorated reinforcing steel shall be removed and replaced as directed by the Contracting Officer.

2.4 MAINTENANCE OF PREPARED SURFACES

After the concrete has been prepared and cleaned, it shall be kept in a clean, dry condition until the repair has been completed. Any contamination, including oil, solvent, dirt accumulation, or foreign material shall be removed by additional wet sandblasting and air-water jet cleanup followed by drying.

SECTION 3 - SPECIFICATIONS FOR REPAIRING CONCRETE

3.1 SURFACE GRINDING

Where bulges, offsets, and other irregularities exceed the specified tolerances, the protrusions shall be repaired so that the surfaces are within the specified limits. Surface grinding techniques may be used for this purpose subject to the following limitations:

a. Grinding of surfaces subject to cavitation erosion (hydraulic surfaces subject to flow velocities exceeding 40 feet per second) shall be limited in depth so that no aggregate particles are exposed more than 1/16 inch in cross section at the finished surface.

b. Grinding of surfaces exposed to public view shall be limited in depth so that no aggregate particles are exposed more than 1/4 inch in cross section at the finished surface.

c. Grinding of all other surfaces shall be as directed by the Contracting Officer. In no event shall surface grinding result in exposure of more than one-half the diameter of the maximum-size aggregate.

d. Where surface grinding has caused or will cause exposure of aggregate particles greater than the limits of subparagraph 3.1.a. or b., the concrete shall be repaired by excavating and replacing the concrete in accordance with paragraph 3.6 or 3.8. as directed by the Contracting Officer.

3.2 PORTLAND CEMENT MORTAR

a. General. - Repairs with portland cement mortar shall be made only if specifically approved by the Contracting Officer. Approval for hand-applied cement mortar repairs will be given only for very small repair areas not associated with critical performance of the structure. When approved, portland cement mortar may be used for repairing defects on exposed, new concrete surfaces if the defects are small and are too wide for dry pack and too shallow for concrete replacement and only if the repairs can be completed within 24 hours of removing the forms. Portland cement mortar shall not be used for repairs to old or existing concrete or for repairs that extend to or below the first layer of reinforcing steel.

b. Submittals. - Before beginning any repair work, the Contractor shall submit a detailed list of the equipment, procedures, and materials the Contractor proposes to use for cement mortar repair to the Contracting Officer for approval.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - Portland cement mortar shall consist of type I or type II portland cement, clean water, and clean, well-graded sand passing a 1.18-mm (No. 16) sieve. All mortar materials, including curing compound shall meet the requirements of subparagraph 3.6.d.

e. Safety. - All work shall be performed in accordance with the requirements of paragraph 1.6.

f. Concrete preparation. - After damaged or defective concrete has been removed as specified in section 2, the surface on which mortar is to be placed shall be prepared by being thoroughly cleaned of all micro fractured, loose, or deteriorated materials and surface-dried.

g. Application and Mixture Proportioning. - Portland cement mortar shall be composed of portland cement, sand, and water, all well mixed and brought to proper consistency. Mortar mixtures and application techniques shall be in accordance with the requirements for mortar replacement method as described in Reclamation's "Concrete Manual", Eighth Edition, revised, chapter VII. Cement mortar shall not be applied until approval of all submittals has been received from the Contracting Officer.

h. Curing. - All cement mortar repairs shall be water cured for 7 days following application. At no time during this initial curing period shall the mortar be allowed to dry. If drying occurs, the repair shall be removed and replaced. If the repair is removed and the original concrete is older than the maximum specified in subparagraph 3.2.a., another repair method shall be used in accordance with these specifications. Following the 7-day curing period and while the repair is still saturated, the surface of the repair shall receive two coats of wax-base (type I) or water-emulsified resin base (type II) curing compound meeting the requirements of subparagraph 3.6.d.

3.3   DRY PACK AND EPOXY BONDED DRY PACK

a. General. - The dry pack concrete repair technique shall be limited to areas that are small in width and relatively deep, such as core holes, holes left by the removal of form ties, cone-bolt and she-bolt holes, and narrow slots cut for repair of cracks. Epoxy bonded dry pack shall be used for critical repairs or for repairs expected to be exposed to severe service conditions. Dry pack shall not be used for shallow depressions where lateral restraint cannot be obtained, nor for filling behind steel reinforcement.

b. Submittals. - Before beginning any repair work, the Contractor shall submit to the Contracting Officer for approval, data for the mortar materials and as provided by paragraph 3.8.b.(2).

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - Dry pack mortar shall consist of type I or II portland cement, clean sand that will pass a 1.18-mm (No. 16) sieve, and clean water. All dry pack materials, including curing compound, shall meet the requirements of subparagraph 3.6.d. Epoxy bonding resin shall meet the requirements of paragraph 3.8.d.(2).

e. Safety. - All work shall be performed in accordance with the requirements of paragraph 1.6.

f. Concrete preparation. - Holes for dry pack shall have a minimum depth of 1 inch and shall be square at the surface edge. A careful inspection shall be made to ensure that the hole is thoroughly clean and is in sound concrete. The interior surfaces of the hole shall be presoaked prior to application of the dry pack. If epoxy bonded dry pack is to be used presoaking the repair area prior to application of the dry pack shall not be performed.

g. Application. - A mortar bond coat or epoxy resin bond coat shall be applied to the concrete hole surface prior to placing dry pack. The mortar bond coat shall consist of 1 part portland cement to 1 part sand mixed with water to give a fluid paste consistency. The mortar bond coat shall be thoroughly brushed onto the hole surfaces. The epoxy resin bond coat shall consist of materials and be applied in accordance with the provisions of paragraph 3.8.g.(3). Dry pack mortar shall consist of 1 part portland cement to 2.5 parts sand (by weight) and shall be mixed with just enough water so that the mortar will stick together when molded by hand and not exude water when squeezed.

The dry-pack mortar shall be immediately packed into place in 3/8-inch compacted layers before the bond coat has dried or cured.

Each layer shall be compacted over the entire surface by tamping with a hardwood dowel and hammer. Hardwood dowels are used in preference to metal bars because the bars tend to polish the surface of each layer. The final layer shall be finished immediately after compaction by laying the flat side of a hardwood board against the fill and striking the board firmly with a hammer.

h. Curing. - Proper curing is essential for a successful dry-pack repair. The surface of the repair area shall be protected from drying and shall be kept continuously moist for 7 days. The surface of the repair shall be protected from surface drying by using burlap kept wet, wet sand, or plastic sheeting over a water soaker hose, or other methods approved by the Contracting Officer. After 7 days and while the surface is still damp, two coats of curing compound shall be applied to prevent moisture loss. The dry-pack repair area shall not be exposed to freezing temperatures for 3 days after application of the curing compound.

3.4 PREPLACED AGGREGATE CONCRETE

a. General. -

(1) Preplaced aggregate concrete (PAC) is concrete that has been made by forcing a grout into the voids of a mass of clean, graded, coarse aggregate. As a repair method, PAC is used where placing conventional concrete is extremely difficult, such as in underwater repairs, concrete and masonry repairs, or where shrinkage of concrete must be kept to a minimum. In underwater repairs, injection of grout at the bottom of the PAC displaces water, leaving a homogeneous mass of concrete with a minimum of paste washout.

For the purpose of this repair method, grout is defined as a mixture of water, cementitious materials, sand, and admixtures.

(2) Reference standards and specifications for PAC. - Reference standards and specifications for materials, testing, and proportioning PAC shall be the standards listed below. Standards and specifications for testing concrete and concrete materials shall be in accordance with applicable ASTM and ACI standards.

(a) ASTM C 937 - Standard Specification for Grout Fluidifier for Preplaced-Aggregate Concrete.

(b) ASTM C 938 - Standard Practice for Proportioning Grout Mixtures for Preplaced-Aggregate Concrete.

(c) ASTM C 939 - Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method).

(d) ASTM C 940 - Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory.

(e) ASTM C 941 - Standard Test Method for Water Retentivity of Grout Mixtures for Preplaced-Aggregate Concrete in the Laboratory.

(f) ASTM C 942 - Standard Test Method for Compressive Strength of Grouts for Preplaced-Aggregate Concrete in the Laboratory.

(g) ASTM C 943 - Standard Practice for Making Test Cylinders and Prisms for Determining Strength and Density of Preplaced-Aggregate Concrete in the Laboratory.

(h) ASTM C 953 - Standard Test Method for Time of Setting of Grouts for Preplaced-Aggregate Concrete in the Laboratory.

(i) American Concrete Institute Standard (ACI-304), Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete.

b. Submittals. -

(1) At least 60 days prior to beginning repair work, the Contractor shall submit for approval a repair plan for PAC construction. The repair plan shall include detailed drawings of formwork construction, the grout injection system including sequence of injecting grout into insert pipes, location and spacing of injection tubes, sounding wells, and pipes; a description of all equipment including pumps, sizes and diameters of pipes, hoses, and connections; the planned operating procedures and pumping rates for grout; methods of placing coarse aggregate; methods of consolidating aggregates and PAC during grouting; and communication facilities between the grout mixing and pumping plant and PAC placement.

The proportions of grout mixtures and fresh properties of grout shall be submitted with the repair plan. Included with the grout proportions, shall be the voids content and compacted density of aggregates before injection of grout, the density of hardened PAC, and the compressive strengths of PAC at 7 and 28 days' age.

(2) The Contractor shall submit for approval to the Contracting Officer's representative a proposed specific operating procedure including a hazard analysis for all preplaced aggregate concreting and grout injecting operations. The specific operating procedure shall include such things as engineering controls, protective clothing, eye protection, respiratory protection, and air sampling as necessary to check the effectiveness of the control program.

(3) Pump rating curves and complete mixer details, including photographs or drawings of the proposed mixing equipment, shall be submitted to the Contracting Officer for approval 30 days prior to use. The Contracting Officer shall have the right to require the Contractor to make changes in the equipment which the Contracting Officer determines necessary to make the equipment perform satisfactorily during the grouting operations without additional cost to the Government

(4) The Contractor shall submit test results from testing of cylinders in accordance with the requirements of subparagraph c. below.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications. Unless otherwise directed, grout mixtures shall be proportioned in accordance with ASTM C 938.

For normal structural work, the ratio of cementitious materials (cement plus pozzolan) to sand shall be 1:1. If leaner mixes are required (generally for low heat generation), the ratio may be adjusted, but shall not exceed 1:2.

The ratio of cement to pozzolan, by weight, shall be between 2:1 and 4:1 as directed by the Contracting Officer.

The ratio of water to cementitious materials

$$\frac{W}{P+C}$$

where:
W = weight of water
P = weight of pozzolan
C = weight of concrete

shall not exceed 0.50 by weight. For severe exposure conditions, the W/P+C ratio shall be in accordance with Reclamation's "Concrete Manual," Eighth Edition, revised, chapter III, table 15.

The pumpability of grout containing fine sand (grading 1, table 2 of ASTM C 637) shall be controlled by the consistency test using the flow cone in accordance with ASTM C 939. The flow time shall be between 20 and 30 seconds unless it can be demonstrated that grout can be effectively pumped at a different flow time.

Compressive strength cylinders shall be cast in accordance with ASTM C 943 and tested at 7 and 28 days' age with a minimum of two cylinders tested for each age. The design compressive strength of PAC shall be 4,000 pounds per square inch at 28 days' age. The required average strength for PAC is that which will ensure that 80 percent of all test cylinders exceed the design strength.

The quality of the top of formed PAC placements shall be ensured by venting air, water, and low-quality grout from the uppermost location in the placement.

For unformed surfaces where a screeded or troweled finish is required, the grout level shall flood the top surface above any aggregate, and any diluted grout shall be removed by brooming. A thin layer of pea gravel having a maximum-size aggregate (MSA) of 3/8 inch shall be worked into the surface by raking and tamping or internal vibration. The surface shall be finished in accordance with conventional concrete procedures to resemble the finish of the surrounding concrete. Care shall be taken when topping off the unformed surface to avoid lifting or loosening of the surface aggregate.

d. Materials. - Materials for PAC shall be in accordance with the requirements of ASTM C 938 and the following additional requirements:

(1) Pozzolan. - Pozzolan shall meet the requirements of ASTM C 618 for class F pozzolan.

(2) Admixtures. -

(a) Air-entraining admixture. - Air-entraining admixture (AEA) shall meet the requirements of ASTM C 260.

The amount of AEA used for injecting mortar shall be that amount necessary to effect a total air content in the mortar, prior to injection, of 9 percent, plus or minus 1 percent, by volume of mortar.

(b) Grout fluidifier. - Grout fluidifier shall meet the requirements of ASTM C 937.

(c) Chemical admixtures. - Chemical admixtures, if permitted, shall meet the requirements of ASTM C 494 for types A, D, F, or G admixtures. Chemical admixtures shall not be used without prior approval from the Contracting Officer.

(3) Sand. - Sand shall consist of natural particles which may be supplemented by limited quantities of crushed sand to make up for deficiencies in the natural materials. Natural sand is required due to its favorable particle shape for pumping grout. Sand for PAC differs from sand used for conventional concrete, primarily in its finer grading.

Sand shall meet the quality requirements of subparagraph 3.6.d.; and the grading requirements of ASTM C 938.

(4) Coarse aggregate . - Coarse aggregate shall be clean and well-graded. Unless otherwise directed, the MSA shall be 1-1/2 inches, and after compaction in the forms, shall have a voids content from 35 to 45 percent.

Coarse aggregate shall meet the quality requirements of subparagraph 3.6.d.; and, the grading requirements of ASTM C 637, table 2, grading 1 for coarse aggregate.

For larger placements, the largest size aggregate that can economically be placed shall be used. The MSA and grading of coarse aggregate for these placements should follow the guidelines of ACI 304.

e. Safety. - All work shall be performed in accordance with requirements of paragraph 1.6 and these specifications.

The Contractor shall comply with Reclamation's "Construction Safety Standards" as well as all other applicable safety and health standards and regulations. In the event of conflict, the more stringent standard shall apply.

f. Concrete preparation. - The Contractor shall prepare all concrete surfaces and foundations for PAC application. Concrete surface preparation shall be in accordance with subparagraph 3.6.f.

For underwater repairs, high-pressure water jetting shall be the normal method for concrete removal and surface scarification. Low-pressure water jetting will be allowed for cleanup immediately before placing PAC.

In underwater construction where contamination is known or suspected to exist, the water shall be sampled and tested to determine the degree of contamination and its possible influence on the quality of concrete. Where moderate contamination is present, concrete surfaces shall be cleaned within 2 days prior to placing aggregate and grouting. If contaminants are present in such quantity or are of such character that harmful effects cannot be eliminated or controlled, preplaced aggregate concrete shall not be used.

All loose, fine material shall be removed from the placement insofar as possible before placement of coarse aggregate to prevent subsequent coating of the aggregate or filling of voids.

g. Application. -

(1) General. - Application of PAC shall include construction and placement of formwork and the grout injection system, placement of aggregate, injection of grout, finishing, and curing of PAC.

(2) Equipment. - The grout mixing, pumping, and injection system shall be furnished by the Contractor.

The grout injection system shall be designed to deliver and inject grout into the preplaced aggregate, to provide a means for determining the grout elevations within the aggregate mass, and to provide vents in enclosed forms for water and air to escape. The injection system shall have a bypass for returning grout to an agitating tank.

Pumps shall be of a positive displacement type and be equipped with a pressure gauge on the outlet line to indicate any incipient line blockage. At least one extra pump shall be on standby to maintain continuous pumping operations. The pumps shall have quick-disconnecting fittings to the grout supply line.

Mixing and agitating equipment shall be sized to maintain a continuous, uninterrupted flow of grouting mortar for the duration of the PAC placement. The mixing plant shall be a high-speed centrifugal type and shall be equipped with an accurate water meter, reading cubic feet to tenths of a cubic foot. In addition to the grout mixer, a holdover mechanical agitator tank of similar volume as the mixer shall be provided. Suitable provisions shall be made for passing the grout through a U.S. Standard 2.36-mm (No. 8) sieve as it is discharged from the mixer.

The batching and mixing plant equipment shall accurately measure the amounts of cement, pozzolan, sand, admixtures, and water batched for grout. Inaccuracies in feeding and measuring during operation shall not exceed by individual weight plus or minus 1 percent for water; plus or minus 2 percent for cement, pozzolan, or sand; and plus or minus 3 percent for admixtures.

The length of delivery line shall be kept to a practicable minimum. Pipe sizes shall be designed so that during operation, the grout velocity ranges between 2 and 4 feet per second for delivery lines up to 300 feet, or at a pumping rate of about 1 cubic foot of grout per minute through a 1-inch-diameter pipe. Pipe sizes shall be approximately 1 inch in diameter, but may need to be increased in size for delivery lines longer than 300 feet to reduce pressures.

Grout insert pipes shall have a diameter of 3/4 to 1 inch and shall be placed vertically, horizontally, or at angles to inject grout at the proper location. Grout insert pipes shall be in sections about 5-1/2 feet in length for ease of withdrawal. For depths greater than 15 feet, grout insert pipes shall be flushed coupled. For depths less than 15 feet, standard pipe couplings may be used.

Connections between grout delivery lines and insert pipes shall have quick-disconnect fittings. Quick-disconnect fittings which reduce the cross section of the flow area shall not be used. Each insert pipe, or the end of the delivery line where it attaches to the insert pipe, shall be equipped with an individual valve to control or stop the flow of grout. Valves shall be of a quick-opening, plug type which can readily be cleaned.

For vertical and angled injection tube placements, sounding wells shall be used to determine the level of grout in the placement. Sounding wells shall consist of slotted pipe with a diameter of about 2 inches. A 1-inch-diameter float, weighted so that it will float on grout and sink in water (for underwater placements), shall be attached to a sounding line and float freely in the sounding well.

(3) Formwork. - Forms for PAC may be of wood, steel, or other materials suitable for conventional concrete. Wood forms or other materials which may swell or become damaged by submergence in water shall not be used for underwater repairs.

Joints and any entry holes for bolts, reinforcement, injection ports, vents, or injection wells shall be caulked to eliminate grout leakage.

Forms shall be designed to resist the lateral pressure exerted by aggregates during and after placing, and to resist full hydraulic pressure of the concrete throughout placing until initial setting has begun.

Form vibrators for consolidation shall be mounted so that vibration does not loosen bolts and joints which may lead to grout leakage or failure. Form vibrators shall be mounted on ribs or stiffeners attached to the sheathing to effectively transmit vibration to the concrete.

All forms shall be coated with a suitable bond breaker for ease of removal without damaging concrete. For underwater repairs, the bond breaker shall be selected so that it does not wash off the forms during submergence. Formwork, injection tubing, inspection wells, and other equipment shall be protected from damage by aggregates during placing.

Reinforcing steel shall be installed during construction of formwork and securely held in place during placement of aggregate and injection of grout.

(4) Grout pipe system. - The grout pipe system shall be furnished by the Contractor and shall consist of a series of regularly spaced injection tubes with outlets beginning at the bottom and continuing to the top of the compacted aggregates. Observation wells shall be spaced at regular intervals between the injection tubes. Vent pipes shall be used in forms that contain restricted or irregular spaces where water or air may be entrapped by the rising grout surface, such as blockouts or embedment work.

The grout pipe system shall be designed to inject grout beginning at the lowest point in the PAC placement and continue to raise the grout level within the mass by selectively withdrawing the pipes and switching to other pipes to maintain the grout at a gently sloping to nearly horizontal level. The grout pipe system shall be coded to clearly identify the location of the outlet of the pipe supplying grout and the order of supplying grout to the pipes.

The spacing of grout insert pipes shall be between 4 and 12 feet and should average approximately 6 feet. The outlet of grout insert pipes shall begin not more than 6 inches above the bottom of the aggregate mass. Rows of horizontal pipes should be not more than 6 inches above the next lower row of pipes.

As a guide for layout of insert pipes, it can be assumed that the grout surface will have a 1:4 (vertical to horizontal) slope in the dry and a l:6 slope under water.

For vertical and inclined injection systems, sounding wells shall be spaced to observe the level of grout. The ratio of number of sounding wells to insert pipes shall be between 1:4 and not less than 1:10. Sounding wells shall be placed vertically or near vertically.

The delivery line shall consist of a single pipeline extending from the pump to the insert pipe equipped with a valve, or to a wye branching to two insert pipes equipped with valves at the beginning of the wye and at both outlets. A manifold system in which more than one grout insert is operative at the same time shall not be used.

(5) Aggregate preparation and placement. - Coarse aggregate shall be washed and screened immediately before placing in the forms. If more than one size of coarse aggregate is used, the aggregate shall be batched and mixed in the proper proportions or discharged at proportional rates onto a vibrating deck or revolving wash screens.

Coarse aggregate shall be transported to the forms by buckets, conveyors, or other approved methods. Coarse aggregates shall be dumped as close as possible to their final location. A flexible rubber elephant trunk (tremie) shall be used to limit free fall to less than 5 feet to minimize segregation and breakage of aggregate. For large placements, a gated pipe with a diameter at least four times the MSA shall be used. The pipe shall be gradually filled and lowered toward the point of placement, and after the pipe is completely filled at the upper end, aggregate shall be discharged from the lower gate. Aggregate shall not be discharged through an unfilled or partially filled pipe.

Coarse aggregate shall be dumped and spread in nearly horizontal lifts, each lift not to exceed 1 foot in height. Around closely spaced embedded items, such as reinforcing steel, conduits, and blockouts, and in more difficult placements where high density and exceptional homogeneity of concrete are desired, the lift height shall be limited to no more than 4 inches and may have to be placed by hand. Vehicular traffic shall not be permitted on top of preplaced coarse aggregate, with the exception of small skips or loaders and only with approval of the Contracting Officer. This equipment shall have rubber tires and be cleaned of any loose debris or substances that may contaminate aggregates or interfere with grout travel during injection.

Although coarse aggregate shall be completely washed prior to placing it shall not be flushed with water in the forms for the purpose of washing.

If water is used for the purpose of precooling aggregate or to provide lubrication for grout, the water shall be injected through the preplaced grout insert pipes rather than on top of the aggregates.

(6) Grout injection. - Injection shall begin at the lowest insert pipe point within the form and continue to raise the level of grout evenly to the top of the mass of aggregate. The injection process shall raise the level of grout approximately 18 to 24 inches above the outlet of the insert pipe before withdrawing of that pipe begins. Thereafter, the level of grout shall remain a minimum of 12 inches above the outlet of the insert pipe until the injection is completed.

Grouting shall proceed at only one insert pipe at a time. If a wye or manifold system is used, the system shall be equipped with individual valves to control the flow to each insert pipe.

Before the insert pipe is withdrawn, the valve at the pipe inlet shall be shut off. The delivery pipe may then be disconnected to inject at other locations.

When injection insert pipes are placed horizontally, the process shall begin at the lowest insert pipe. Adjacent insert pipes shall have valves opened both alongside and above the pipe being injected. When grout begins to flow out of these pipes, they shall be shut off and grouting continued so that the adjacent pipes are completely submerged. The initial pipe shall then be shut and the process shall be repeated, traveling in a horizontal direction before proceeding to the upper row.

Grout shall not be allowed to set up in the insert pipes between injections. If the injection process is expected to continue for an extended period, a suitable retarding admixture shall be used in the grout. Vertical insert pipes may be rodded to remove grout prior to reinjection; however, insert pipes shall not be cleaned by injecting water through them.

The rate of grout rise and rate of grout injection shall be controlled within the form so that excessive form pressures are not created and so that grout does not cascade within the mass. This is particularly important when grouting under water to avoid sand streaks and honeycombing within the mass.

When grouting around embedded items and particularly under flat surfaces or recessed areas, the grout shall be injected until good quality grout is forced from vent pipes. Good quality grout shall be grout that is not diluted and free from sand, silt, trash, and other items. The rate of flow of grout and grout injection pressures shall be closely monitored in enclosed locations to avoid form failure.

Form vibration shall be used to consolidate grout and remove entrapped air pockets adjacent to form surfaces. Excessive form vibration which causes sand streaking shall not be done. Internal vibration shall not be used for consolidation of the aggregate-grout mixture, but may be used for topping off unformed surfaces.

Unplanned construction joints shall not be used without approval from the Contracting Officer. If a breakdown occurs that stops placement, the grout insert tubes shall be withdrawn, and the grout surface shall be considered a cold joint. Cold joints shall be treated by first removing coarse aggregate down to the joint surface, removing aggregate and poor-quality mortar, and then cleaning the joint surface by approved methods, taking care not to undercut exposed aggregates.

h. Curing. - Curing and protection of PAC shall be in accordance with subparagraph 3.6.h.

3.5 SHOTCRETE

a. General. - Shotcrete is defined as pneumatically applied concrete or mortar placed directly onto a surface. The shotcrete shall be composed of water, cementitious materials, sand, coarse aggregate, steel fibers (if specified), and admixtures, and shall be placed by either the dry-mix or wet-mix process as specified herein.

The dry-mix process shall consist of thoroughly mixing the solid materials; feeding these materials into a mechanical feeder or gun; carrying the materials by compressed air through a hose to a special nozzle; introducing the water and intimately mixing it with the other ingredients at the nozzle; and then jetting the mixture from the nozzle at high velocity onto the surface to receive the shotcrete.

The wet-mix process shall consist of thoroughly mixing all the ingredients with the exception of the accelerating admixture, if used; feeding the mixture into the delivery equipment; delivering the mixture by positive displacement or compressed air to the nozzle; and then jetting the mixture from the nozzle at high velocity onto the surface to receive the shotcrete.

The equipment used by the Contractor for mixing and applying shotcrete shall be capable of handling and applying shotcrete containing the specified maximum-size coarse aggregate. All equipment, including mixers, hoses, nozzles, nozzle liners, air- and water-pressure gauges, and gaskets, shall be maintained in clean and proper operating condition satisfactory to the Contracting Officer.

b. Submittals. - The Contractor shall submit for approval to the Contracting Officer a proposed specific operating procedure including a hazard analysis for all shotcrete operations. The specific operating procedure shall include such things as engineering controls, protective clothing, eye protection, respiratory protection, and air sampling as necessary to check the effectiveness of the control program.

The Contractor shall submit the specimens extracted from panels fabricated for preapplication testing.

The Contractor shall submit test specimens of fresh and hardened concrete from locations directed by the Contracting Officer.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications. The Government will perform all testing of fresh and hardened shotcrete. The Contractor shall obtain specimens from locations specified by the Government. The compressive strength of the shotcrete will be determined through the medium of tests of 3- by 3-inch cores or 3-inch cubes. The average compressive strength of specimens taken from a shotcrete application shall be not less than:

(1) Four thousand pounds per square inch at 28 days' age.

(2) Six hundred pounds per square inch at 8 hours' age. This will be determined from 3-inch cubes extracted from test panels.

Adjustments shall be made as directed by the Contracting Officer to obtain shotcrete having suitable impermeability, strength, density, and durability. Suitable strength is that which will ensure that 80 percent of all test specimens exceed or equal the average strength as specified above.

(3) Preapplication testing of shotcrete and nozzlemen. - No shotcrete shall be applied to the work until preapplication testing indicates that the nozzleman is qualified and the proposed shotcrete mixture meets the specified compressive strength. The Contractor shall allow adequate lead time for fabricating of test panels and testing shotcrete specimens. Furthermore, the Contractor is encouraged to fabricate panels for several mixtures since failure of a single mixture to meet specified strength requirements could delay accomplishment of other work.

(a) Shotcrete mixture. - At least 30 days prior to application of shotcrete to the work, the Contractor shall fabricate two test panels for each mixture to be used for vertical and overhead positions of application.

Application of shotcrete to test panels may be accomplished at locations other than the construction site provided:

(aa) Equipment used for fabricating test panels is identical to that to be used in application.

(bb) The materials used in fabricating test panels are from the same sources as those to be used in application and meet all specifications requirements.

(cc) Application is made in the presence of the Contracting Officer by a nozzleman who will later apply the shotcrete to the work.

Test panels shall be fabricated by applying shotcrete in one application not less than 4 inches thick to a panel form made of plywood or other suitable material.

The panel form to be used for vertical and overhead applications shall be either of two types as follows:

(dd) Open ended on at least two sides with 90E edges on enclosed sides. The minimum size of this open-ended panel shall be 18 inches square.

(ee) Enclosed on all four sides with members that taper outward in a manner that prevents the accumulation of rebound at edges and corners while allowing a shotcrete thickness of not less than 4 inches over the entire flat area of the panel. The minimum size of the center flat area of panels enclosed by tapered edges shall be 15 inches square.

Panels should be stiffened and weighted sufficiently to provide rigid surfaces against which the shotcrete can be applied. The panels shall contain the same type of reinforcement as to be used in construction to indicate whether sound shotcrete is obtained without shadowing behind the reinforcement.

After fabrication, the panel shall, except when test specimens are being obtained, be covered and sealed with polyethylene sheeting or shall be cured by any other approved method that will prevent loss of moisture.

The Contractor shall provide all necessary equipment and shall obtain 3-inch cubes from the test panels for testing the compressive strength at 8 hours' age and shall obtain 3-inch cubes or 3-inch-diameter cores from test panels for testing the compressive strength at 28 days' age.

All core drilling and saw cutting of cubes shall be performed in a workmanlike manner by competent and experienced workmen. Test specimens shall be extracted at the latest time, satisfactory to the Contracting Officer, that the specimens can be delivered by the Contractor to the Government for testing at the specified age. At least five specimens shall be obtained from each of the panels for each mixture being verified. Extreme care shall be taken in drilling cores or cutting cubes to obtain specimens satisfactory to the Contracting Officer.

Cores shall be 3 inches in diameter, drilled the full depth of the shotcrete; they shall be straight, sound, of uniform diameter, and of sufficient length for subsequent trimming by the Contractor to produce a right cylinder with an L/D ratio of 1.0 plus or minus 0.03.

Cubes shall be cut full depth of the shotcrete, shall be sound, and shall have six uniform square sides of 3-inch length plus or minus 0.05 inch.

Immediately after extraction, test specimens shall be individually wrapped and sealed in polyethylene bags or covered and sealed by any other approved means to prevent loss of moisture. Each test specimen shall be properly marked for identification.

Each set of test specimens shall be delivered without delay to the project laboratory, or other location approved by the Contracting Officer, for testing at the specified age.

(b) Shotcrete nozzleman. - The nozzleman who applies shotcrete shall be certified with the materials and equipment to be used for the work. Certification shall be in accordance with ACI 506.3R with the following limitations:

(aa) The certification examination will be conducted by authorized representative of the Contracting Officer.

(bb) The examination will consist of an oral test and a field workmanship demonstration test.

(cc) The test panels shall be a minimum of 18 inches square and 4 inches deep. The sides may have beveled edge forms (45E angle out to reduce the entrapment of rebound in the corners).

(dd) Test specimens shall be of the size and shape specified for quality control in these specifications.

d. Materials. -

(1) Portland cement. - The cementitious materials in shotcrete shall comply with subparagraph 3.6.d.(1), with the exception that type III cement may be approved for use if sulfate conditions do not exist.

(2) Water. - Water shall be in accordance with subparagraph 3.6.d.(4).

(3) Sand and coarse aggregate. - Except as hereinafter provided for coarse aggregate grading, the sand and coarse aggregate shall be in accordance with subparagraph 3.6.d.(5).

The maximum-size coarse aggregate shall be no larger than 3/8 inch. No material retained on the 3/8-inch sieve shall be permitted. Only 3 percent significant undersize aggregate material that will pass a 4.75-mm (No. 4) U.S. Standard sieve will be permitted.

(4) Admixtures. - Admixtures shall be in accordance with subparagraph 3.6.d.(3).

(a) Accelerator. - The Contractor may use an accelerating admixture in shotcrete.

(b) Air-entraining admixture. - The amount of air-entraining admixture used for the wet-mix process shall be that amount necessary to effect a total air content in the shotcrete, prior to application, of 7 percent plus or minus 1 percent by volume of shotcrete.

(5) Steel fibers. - Where directed by the Contracting Officer, the Contractor shall furnish steel fibers for reinforcement. The amount of steel fibers used shall be 90 pounds of fiber per cubic yard of shotcrete.

Steel fibers shall be carbon steel deformed type I (cold drawn wire) or type II (cut sheet) to conform to the requirements of ASTM A 820. Length of steel fiber shall be 3/4-inch minimum to 1-1/4-inch maximum. The length divided by diameter (or equivalent diameter), or aspect ratio, shall be 45 minimum and 100 maximum. The steel fiber shall have a minimum average tensile strength of 50,000 pound-force per square inch.

(6) Curing compounds. - Curing compounds shall meet the applicable requirements of subparagraph 3.6.d.(6).

e. Safety. - All work shall be performed in accordance with the requirements of paragraph 1.6.

f. Concrete preparation. - Concrete to be repaired with shotcrete shall be prepared in accordance with section 2.

g. Application. -

(1) Mixture proportions. - The proportions of water, cementitious materials, sand, coarse aggregate, and admixture and fibers, if used, shall be determined by the Contractor subject to approval by the Contracting Officer to obtain the specified compressive strength and bond. The shotcrete shall have a minimum cementitious materials content of 658 pounds per cubic yard, as discharged from the nozzle. Furthermore, the amount of cementitious materials will be increased by

the Contracting Officer as necessary to obtain the specified compressive strengths and bond.

(2) Consistency. - The consistency of the dry-mix process shotcrete shall be regulated by the amount of water introduced at the nozzle and shall be adjusted so that the in-place shotcrete is adequately compacted and neither sags nor shows excessive rebound.

The consistency of the wet-mix process shotcrete at the delivery point shall not exceed a 3-inch slump.

(3) Batching. - Batching for the dry-mix process shall be as specified in this paragraph. Water, cementitious materials, sand, coarse aggregate, admixture, and fibers shall be volume proportioned by controlled, calibrated, screw conveyor, or other methods of feed, provided uniform proportions are obtained. The equipment shall be capable of controlling the delivery of material so that inaccuracies do not exceed 1 percent for water; 1-1/2 percent for cementitious materials; 2 percent for sand and coarse aggregate; and 3 percent for admixture and fibers. If these limits cannot be consistently met, then batching shall be by direct weighing.

To ensure accurate, consistent proportioning of aggregate, augers used in dry-mix process shotcrete delivery equipment shall be constructed of abrasion-resistant material to prevent rapid and excessive wear. Auger feed shall be recalibrated as necessary to keep them within the prescribed batching accuracy percent.

The percentage of surface moisture in the sand (ASTM C 566) shall be 3 to 6 percent, by weight, and shall be controlled within this range as may be necessary to maintain uniform feed and to avoid choking the delivery equipment.

Shotcrete batches containing cementitious materials that have been in contact with damp aggregate or other moisture for more than 2 hours shall be wasted at the Contractor's expense.

Batching for the wet-mix process shall be in accordance with the requirements for concrete batching under subparagraph 3.6.g.

When batching with fibers the Contractor shall obtain a good blend of fibers throughout the shotcrete. The Contractor shall furnish appropriate equipment or develop a suitable technique for dispersing the fibers in the mixer free of fiber clumps. A suggested guide is ACI 544.3R.

(4) Mixing. - Mixing for the wet-mix and the dry-mix process shall be as specified in this paragraph. Cementitious materials, sand, coarse aggregate, admixtures, and steel fibers shall be uniformly added and thoroughly mixed by machine before being fed into the delivery equipment.

Mixers used to mix dry ingredients shall discharge the batch without segregation. Mixers shall be tested for uniformity of coarse aggregate content from front to back of the mixer. The maximum permissible difference in percentage of coarse aggregate by weight of sample shall not exceed 6 percent within a batch.

The discharge nozzle for the dry-mix process shall be equipped with a manually operated water injection system of sufficient pressure to provide an even distribution of water into the dry shotcrete mixture at the nozzle. The water valve shall be capable of ready adjustment to vary the quantity of water and shall be convenient to the nozzleman.

(5) Placing. - Placing shotcrete shall be performed only by a nozzleman certified in accordance with subparagraph 3.5.c.(3) during preapplication testing.

An air compressor with ample capacity to provide clean, dry air and maintain a uniform nozzle velocity shall be used for applying shotcrete.

The shotcrete shall be applied by pneumatic pressure from a discharge nozzle held about 2 to 5 feet from the surface and in a stream as nearly normal as possible to the surface being covered. The nozzle shall also be rapidly gyrated while applying the shotcrete.

The shotcrete shall be applied in layers having a thickness that will ensure complete adherence of the shotcrete to the surface. Any shotcrete that shows evidence of sloughing or separation shall be removed and replaced by and at the expense of the Contractor and to the satisfaction of the Contracting Officer.

Care shall be taken to prevent the formation of sand pockets in the shotcrete. Any sand pockets formed shall be removed immediately and replaced with suitable shotcrete at the expense of the Contractor.

Use of rebound as shotcrete aggregate is not permitted, and rebound accumulations shall be removed and disposed of at the expense of the Contractor as approved by the Contracting Officer.

The temperature of shotcrete, as placed, shall be between 50 and 90 EF. Shotcrete shall not be applied to frozen surfaces. The applied shotcrete shall be kept at a temperature of at least 50 EF for a minimum of 3 days immediately following application. When cold weather conditions prevail at the job site and the temperature of aggregates and water is below 50 EF, it may be necessary to heat the aggregate and/or water prior to use in the shotcrete to obtain shotcrete meeting the specified 28-day compressive strength.

The Contractor shall provide and maintain sufficient standby equipment to assure continuous production and application of shotcrete.

If, in the Contracting Officer's opinion, the shotcreting system selected by the Contractor fails to provide satisfactory in-place shotcrete in accordance with these specifications, the Contractor shall change to another system of either of the two processes, provide a redemonstration of the nozzleman's proficiency, or provide a new qualified nozzleman.

If, in the Contracting Officer's opinion, the projection of steel fibers (when used) on the face of the finished shotcrete creates a hazard to personnel, a sacrificial coating of no less than 1/2-inch thickness of shotcrete without the steel fibers shall be applied.

h. Curing. - Shotcrete that is applied where the ambient relative humidity is 85 percent or above will not require measures to control the evaporation of water during curing. However, the Contractor shall substantiate that the relative humidity level in the area of application is above 85 percent by furnishing, installing, and maintaining equipment capable of continuously recording relative humidity.

When the relative humidity is less than 85 percent, the Contractor shall initiate an approved curing method immediately after application of the shotcrete.

Curing shall be accomplished by either:

(1) Raising and maintaining the ambient relative humidity above 85 percent, or

(2) Applying a membrane curing compound as specified in subparagraph 3.6.d.(6).

Water curing. - Shotcrete cured with water shall meet the applicable requirements of subparagraph 3.6.h. except the 14-day requirement may be reduced to 7 days.

3.6 CONCRETE REPLACEMENT

a. General. - Concrete replacement shall be used on areas of damaged or unacceptable concrete greater than 1 square foot having a depth greater than 6 inches or a depth extending 1 inch below or behind the backside of reinforcement. Concrete replacement shall also be used for holes extending entirely through concrete sections and for large areas of repair greater than 4 inches in depth when the concrete to be repaired is less than 7 days old. Epoxy bonding agents, latex bonding agents, dry neat cement, cement paste, or cement and sand mortar shall not be used to bond fresh concrete to concrete being repaired by this method.

b. Submittals. - The Contractor shall submit certification of compliance for materials in accordance with subparagraph d. below.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - All concrete materials shall be obtained from previously tested and approved sources. Materials will be accepted on certificate of compliance with the following ASTM Standards:

(1) Portland cement. - Portland cement shall meet the requirements of ASTM C 150 for type I, II, or V cement. The specific cement type shall be as directed by the Contracting Officer and determined by the environment in which the repair is conducted.

(2) Pozzolan. - Pozzolan shall meet the requirements of ASTM C 618 for class F pozzolan.

(3) Admixtures. - The Contractor shall furnish air-entraining and chemical admixtures for use in concrete.

(a) Air-entraining admixture shall be used in all concrete and shall conform to ASTM C 260.

(b) Chemical admixtures. - The Contractor may use type A, D, F, or G chemical admixtures. If used, they shall conform to ASTM C 494.

(4) Water. - The water used in making and curing concrete shall be free from objectionable quantities of silt, organic matter, salts, and other impurities.

(5) Aggregate. - The term "sand" is used to designate aggregate in which the maximum size particle will pass a 4.75-mm (No. 4) sieve. The term "coarse aggregate" is used to designate all aggregate which can be retained on a 4.75-mm (No. 4) sieve. Sand and coarse aggregate meeting the requirements of ASTM C 33 shall be used in all concrete.

(6) Curing compound. - Wax-base (type I) and water-emulsified resin-base (type II) curing compounds shall conform to the requirements of Reclamation's "Specifications for Concrete Curing Compound" (M-30) dated October 1, 1980.

e. Safety. - All work shall be performed in accordance with paragraph 1.6.

f. Concrete preparation. - After damaged or unacceptable concrete has been removed as specified in section 2. the surface on which the replacement concrete will be placed shall be prepared. An acceptable surface shall have the appearance of freshly broken, properly cured concrete. The surface shall be free of any deleterious materials such as free moisture, ice, petroleum products, mud, dust, carbonation, and rust. The perimeters of the repair shall be saw cut to a minimum depth of 1 inch.

The clean surface is not ready to receive repair concrete until it has been brought to a saturated, surface-dry condition. This condition is attained by saturating the surface to a depth that no concrete mixture water may be absorbed from the fresh concrete. Then, just prior to placing concrete against the surface, all free moisture (moisture capable of reflecting light) shall be removed from the prepared surface.

g. Application. - Replacement concrete shall be composed of cement, coarse aggregate, sand, water, and approved admixtures, all well mixed and brought to the proper consistency. Concrete mixtures shall be proportioned in accordance with Reclamation's "Concrete Manual", Eighth Edition, revised, chapter III. The water-cement ratio of the concrete (exclusive of water absorbed by the aggregates) shall not exceed 0.47 by weight. Slump of the concrete, when placed, shall not exceed 2 inches for concrete in slabs that are horizontal or nearly horizontal and 3 inches for all other concrete. Concrete with less slump should be used when it is practicable to do so. The concrete ingredients shall be thoroughly mixed in a batch mixer. The concrete, as discharged from the mixer, shall be uniform in composition and consistency from batch to batch.

(1) Forms. - Forms shall be used for concrete whenever necessary to confine the concrete and shape it to the required lines. The forms shall be clean and free from encrustations of mortar, grout, or other foreign material. Before concrete is placed, the surfaces of the forms shall be coated with a form oil that will effectively prevent sticking and will not soften or stain the concrete surfaces or cause the surfaces to become chalky or dust producing.

(2) Placing. - Placing of concrete shall be performed only in the presence of an authorized representative of the Contracting Officer. Placement shall not begin until all preparations are complete and the authorized representative of the Contracting Officer has approved the

preparations. Concrete shall not be placed in standing or running water unless, as determined by the Contracting Officer, the structure under repair cannot be economically dewatered. If underwater concrete placement is required, special placing procedures shall be required. A suggested guide is ACI 394R.

When appropriate, concrete shall be placed in layers not greater than 20 inches thick. Each layer, regardless of the thickness, shall be adequately consolidated using immersion-type vibrators or form vibrators when approved. Adequate consolidation of concrete is obtained when all undesirable air voids, including the air voids trapped against forms and construction joints, have been removed from the concrete.

(3) Finishing. - The class of finish required shall be a finish closely resembling the finish of the surrounding concrete.

h. Curing and protection. - Concrete repairs shall be cured either by water curing or by use of wax-base (type I) or water-emulsified resin-base (type II) curing compound meeting the requirements of subparagraph 3.6.d.(6). Daily inspection by the Contractor shall be performed to ensure the maintenance of a continuous, water-retaining film over the repaired area. The water-retaining film shall be maintained for 28 days after the concrete has been placed.

Water curing shall commence when the concrete has attained sufficient set to prevent detrimental effects to the concrete surface. The concrete surface shall be kept continuously wet for 14 days.

The Contractor shall protect all concrete against damage until acceptance by the Government. Whenever freezing temperatures are imminent, the Contractor shall maintain the newly placed repair concrete at a temperature of not less than 50 EF for 72 hours. Water-cured concrete shall be protected from freezing for the duration of the curing cycle and an additional 72 hours after the water is removed.

3.7 EPOXY-BONDED EPOXY MORTAR

a. General. - Epoxy-bonded epoxy mortar is defined as freshly mixed epoxy mortar (sand with epoxy binder) that is placed over an epoxy resin bond coat on hardened existing concrete. Epoxy-bonded epoxy mortar repair may be used when the depth of repair is 1-1/2 inches or less. This method may also be used for repair of areas with a depth greater than 1-1/2 inches when those areas are small (less than 1 square foot) and few in number, and where it is impractical to use epoxy-bonded concrete.

Epoxy-bonded epoxy mortar may be used only when:

(1) Moisture in the structure will not collect behind the bond coat and cause damage upon freezing, and

(2) The repair will not be subjected to extremes of temperatures such as those caused by exposure to direct sunlight, extremes of climate, or extremes in water temperature.

All epoxy-bonded epoxy mortar repairs to new construction shall be performed after 7 days from the original placement.

b. Submittals. -

(1) When directed by the Contracting Officer, the Contractor shall submit samples of the epoxy-resin bonding system. The samples shall be submitted at least 30 days prior to use in the work to the Bureau of Reclamation, Attn D-8180, Building 56, Denver Federal Center, West Sixth Avenue and Kipling Street, Denver CO 80225.

(2) Certification of epoxy-bonding agent. - The Contractor shall furnish the Contracting Officer the manufacturer's certification of conformance of the epoxy-resin bonding system with these specifications. The certification shall identify the Reclamation solicitation/ specifications number(s) under which the epoxy is to be used and shall include the quantity represented, the batch numbers of the resin and curing agent, and the manufacturer's results of tests performed on the particular combination of resin and curing agent.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. -

(1) Epoxy resin. - The same epoxy resin system shall be used for both the bond coat and the epoxy mortar. The epoxy resin shall meet the requirements of specifications ASTM C 881 for a type I , grade 2, class B or C or a type III, grade 2, class B or C epoxy system. In addition, it shall be a 100-percent solids system, and no unreactive diluents, wetting agents, or volatile solvents shall be incorporated.

(2) Sand. - The sand for epoxy mortar shall be clean, dry, well-graded sand composed of sound particles passing a 1.18-mm (No. 16) sieve and conform to the following limits:

Sieve	Individual percent, by weight, retained on sieve
600 µm (No. 30)	26 to 36
300 µm (No. 50)	18 to 28
150 µm (No. 100)	11 to 21
pan	[1]25 to 35

[1]Range shown is applicable when 60 to 100 percent of pan is retained on the 75 µm (No. 200) sieve. When 0 to 59 percent of pan is retained on the 75 µm (No. 200) sieve, the percent pan shall be within the range of 10 to 20 percent, and the individual percentages retained on the 600 µm, 300 µm, and 150 µm (Nos. 30, 50, and 100) sieves shall be increased proportionately.

Sand of this grading is not usually commercially available and may have to be produced by the Contractor. Starting with a concrete sand, the oversized particles shall be removed with a 1.18-mm (No. 16) sieve. Individual sieve sizes of sand can be purchased to mix with the remaining sand to meet the required grading. Most sands require at least the addition of more pan material to meet the required grading.

When directed, minor adjustments in sand grading shall be made to provide a suitable epoxy mortar. Other fillers or commercially available sand gradings prepared specifically for epoxy mortars may be used in epoxy mortar on approval by the Contracting Officer.

The sand shall be maintained in a dry area at no less than 60 EF temperature for 24 hours immediately prior to time of use.

e. Safety. - All work shall be performed in accordance with paragraph 1.6 of these specifications. Certain additional safety precautions shall be employed when using uncured epoxy materials. Skin contact with uncured epoxy shall be avoided. Protective clothing, including rubber or plastic gloves, shall be worn by all persons handling epoxy materials. All exposed skin areas that may come in contact with the material shall be protected with a protective barrier cream formulated for that purpose. Adequate ventilation shall be provided and maintained at all times during use of epoxy and epoxy solvents. Fans used for ventilating shall be explosion proof. If necessary, respirators that filter organic fumes and mists shall be worn. If spray application is used, the operator shall wear a compressed air-fed hood, and no other personnel shall be closer than 100 feet if downwind of the operator when spraying is being performed. All epoxy-contaminated materials such as wipes, empty containers, and waste material shall be continually disposed of in containers which are protected from spillage. Epoxy spillage shall be immediately and thoroughly cleaned up. Appropriate solvents may be used to clean tools and spray guns, but in no case shall the solvents be incorporated in any epoxy resin or in the placing operation. Solvents shall not be used to remove epoxy materials from skin. Only soap, water, and rags shall be used for this purpose.

All tools shall be completely dried after cleaning and before reuse. All materials, tools, and containers contaminated with epoxy resin or epoxy curing agent shall be removed from the site for disposal in accordance with appropriate local or Federal regulations.

f. Concrete preparation. - Surface preparation and needed removal of existing concrete shall be as in section 2, except that the saw cut shall be 1 inch or equal to the depth of the repair, whichever is less. For repairs less than 1 square foot in area, the required vertical edge may be accomplished with a pneumatic tool or hydrodemolition equipment in lieu of saw cutting. For minor cosmetic repairs of surface defects less than 2 inches in diameter, surface preparation may be limited to cleaning with a small wire brush, removing dust, and heating in depth. Epoxy paste meeting the requirements of ASTM C 881, grade 3, may be used without a bond coat for minor cosmetic repairs of surface defects less than 2 inches in diameter in lieu of epoxy-bonded epoxy mortar when all of the conditions for use of epoxy mortar are met. Any overfilling of minor surface defects shall be removed by grinding after hardening is complete. Where repairs are exposed to public view, color matching of the repair material to the existing concrete shall be done.

The surfaces of the existing concrete to which epoxy mortar is to be epoxy bonded shall be prepared and maintained in a clean and dry condition. Unless epoxy mortar application to wet concrete surfaces is approved by the Contracting Officer. The existing concrete shall be preheated in depth. Preheating shall be sufficient to drive internal moisture from the repair surface and prevent its return until the bond coat is in place. Preheating shall not cause damage to or instant setting of the bond coat.

g. Application. -

(1) Forms. - Forms shall be used as necessary to prevent slumping or sagging of finished epoxy-bonded epoxy mortar. Such forms shall be covered with polyethylene film, and form oil shall not be used.

(2) Preparation of epoxy resin for bond coat. - The epoxy resin is a two-component material which requires combination of components and mixing prior to use. Once mixed, the material has a limited pot life and must be used immediately. The bonding system shall be prepared by adding the curing component to the resin component in the proportions recommended by the manufacturer, followed by thorough mixing. Since the working life of the mixture depends on the temperature (longer at lower temperature, much shorter at higher temperature), the quantity to be mixed at one time shall be applied and topped within approximately 30 minutes. The addition of thinners or diluents to the resin mixture shall not be done. Both components of class C epoxy shall be stored above 60 EF prior to use.

(3) Application of epoxy resin bond coat for epoxy-bonded epoxy mortar. - Immediately after the epoxy resin is mixed, it shall be applied to the prepared, dry existing concrete at a coverage of not more than 80 square feet per gallon, depending on surface conditions. The area of coverage per gallon of agent depends on the roughness of the surface to be covered and may be considerably less than the maximum specified. The epoxy resin may be applied by any convenient, safe method such as squeegee, brushes, or rollers, which will yield an effective coverage, except that spraying of the materials will be permitted only if an efficient airless spray is used and when the concrete surfaces to receive the agent are 70 EF or warmer, which spray shall be demonstrated as providing an adequate job with minimum overspray prior to approval of its use.

Care shall be exercised to confine the epoxy resin to the area being bonded and to avoid contamination of adjacent surfaces. However, the epoxy bond coat shall extend slightly beyond the edges of the repair area.

Steel to be embedded in epoxy mortar shall be coated with epoxy resin. The steel shall be prepared in accordance with the requirements of section 2 and by removing all loose rust either with a wire brush or by wet sandblasting. The exposed steel shall be completely coated with epoxy resin at the time it is being applied to the concrete surfaces of the repair area.

The applied epoxy resin film shall be in a fluid condition at the time the epoxy mortar is placed. The epoxy resin may be allowed to stiffen to a very tacky condition rather than a fluid condition before epoxy mortar is placed on steep sloping or vertical surfaces, in which case special care shall be taken to thoroughly compact the epoxy mortar against the stiffening bond coat. In the event the bond coat is curing too quickly to meet the placement requirements, a second bond coat shall be applied over the first while the first bond coat is still tacky. If any bond coat has cured beyond the tacky state, it shall be completely removed by sandblasting, and proper cleanup, heating, and drying shall be accomplished and a new bond coat applied.

(4) Placing and finishing. - The epoxy mortar shall be composed of sand and epoxy resin suitably blended to provide a stiff, workable mixture. The epoxy components shall be mixed thoroughly prior to the

application of the bond coat and prior to the addition of the sand. The mixture proportions shall be established, batched, and reported on a weight basis, provided that the dry sand and mixed epoxy may be batched by volume using suitable measuring containers that have been calibrated on a weight basis. If equivalent volume proportions are being used, care shall be taken to prevent confusing them with weight proportions. Epoxy mortar will require approximately 5-1/2 to 6 parts of graded sand to 1 part epoxy, by weight. The Contracting Officer will determine, and adjust where necessary, the mix proportions for the particular epoxy and sand being used. The epoxy mortar shall be thoroughly mixed with a slow-speed mechanical stirrer or other equipment producing equivalent results. The mortar shall be mixed in small-sized batches so that each batch will be completely mixed and placed within approximately 30 minutes from the time the two components for the epoxy resin are combined. The addition of thinners or diluents to the mortar mixture will not be permitted.

The prepared epoxy mortar shall be tamped, flattened, and smoothed into place in all areas while the epoxy bond coat is still in a fluid condition. The mortar shall be worked to grade and given a steel trowel finish. Special care shall be taken at the edges of the area being repaired to ensure complete filling and leveling and to prevent the mortar from being spread over surfaces not having the epoxy bond coat application. Steel troweling shall be performed in a manner to best suit the prevailing conditions but, in general, shall be performed by applying slow, even strokes. Trowels may be heated to facilitate the finishing. The use of thinner, diluents, water, or other lubricant on placing or finishing tools will not be permitted, except for final cleanup of tools. After leveling of the epoxy mortar to the finished grade where precision surfaces are required, the mortar shall be covered with plywood panels smoothly lined with polyethylene sheeting and weighted with sandbags or otherwise braced, or by other means acceptable to the Contracting Officer, until danger from slumping has passed. When polyethylene sheeting is used, no attempt shall be made to remove it from the epoxy mortar repair before final hardening.

Epoxy-bonded epoxy mortar repairs shall be finished to the plane of the surfaces adjoining the repair areas. The final finished surfaces shall match the texture of the surfaces adjoining the repair areas.

h. Curing and protection. - Epoxy-mortar repairs shall be cured immediately after completion of each repair area at not less than 60 EF until the mortar is hard. Post curing shall then be initiated at elevated temperatures by heating, in depth, the epoxy mortar and the concrete beneath the repair. Post curing shall continue for a minimum of 4 hours at a surface temperature not less than 90 EF nor more than 110 EF, or for a minimum of 24 hours at a surface temperature not less than 60 EF nor more than 110 EF. The heat shall be supplied by using portable propane-fired heaters, infrared heat lamps, or other approved methods capable of producing the required temperature and positioned so that the required surface temperatures are obtained.

In no case shall epoxy-bonded epoxy mortar be subjected to moisture until after the specified post curing has been completed.

3.8 EPOXY-BONDED CONCRETE

a. General - Epoxy-bonded concrete is defined as freshly mixed portland cement concrete that is placed over a fluid epoxy resin bond coat on hardened existing concrete. Epoxy-bonded concrete repair may be used when the depth of repair is 1-1/2 inches or greater.

b. Submittals. -

(1) When directed by the Contracting Officer, the Contractor shall submit samples of the epoxy-resin bonding system. The samples shall be submitted at least 30 days prior to use in the work to the Bureau of Reclamation, Attn D-3731, Building 56, Denver Federal Center, West Sixth Avenue and Kipling Street, Denver CO 80225.

(2) Certification of epoxy-bonding agent. - The Contractor shall furnish the Contracting Officer the manufacturer's certification of conformance of the epoxy-resin bonding system with these specifications. The certification shall identify the Reclamation solicitation/ specifications number(s) under which the epoxy is to be used and shall include the quantity represented, the batch numbers of the resin and curing agent, and the manufacturer's results of tests performed on the particular combination of resin and curing agent.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. -

(1) Concrete materials. - The materials and procedures used to prepare and mix concrete for epoxy-bonded concrete repair shall be as specified in subparagraph 3.6.d. except that slump of concrete, when placed, shall not exceed 1-1/2 inches.

(2) Epoxy resin. - The epoxy-resin bonding system shall meet the requirements of specification, ASTM C 881 for a type II, grade 2, class B or C epoxy system. In addition, it shall be a 100-percent solids system and shall not contain unreactive diluents or wetting agents. Volatile solvents shall not be incorporated into the epoxy system.

e. Safety. - All work shall be performed in accordance with paragraph 1.6 and these specifications. Certain additional safety precautions shall be employed when using uncured epoxy materials. Skin contact with uncured epoxy shall be avoided. Protective clothing, including rubber or plastic gloves, shall be worn by all persons handling epoxy materials. All exposed skin areas that may come in contact with the material shall be protected with a protective barrier cream formulated for that purpose. Adequate ventilation shall be provided and maintained at all times during use of epoxy and epoxy solvents. Fans used for ventilating shall be explosion proof. If necessary, respirators that filter organic fumes and mists shall be worn. All epoxy-contaminated materials such as wipes, empty containers, and waste material shall be continually disposed of in containers which are protected from spillage. Epoxy spillage shall be immediately and thoroughly cleaned up. Appropriate solvents may be used to clean tools and spray guns, but in no case shall the solvents be incorporated in any epoxy resin or in the placing operation. Solvents shall not be used to remove epoxy materials from skin. Only soap, water, and rags shall be used for this purpose.

All tools shall be completely dried after cleaning and before reuse.

All materials, tools, and containers contaminated with epoxy resin or epoxy curing agent shall be removed from the site for disposal in accordance with appropriate local or Federal regulations.

f. Concrete preparation. - Concrete to be repaired by epoxy-bonded concrete shall be prepared in accordance with the provisions of section 2, except that the perimeters of the repair shall be saw cut to a minimum depth of 1 inch. Epoxy-bonded concrete shall not be applied to concrete surfaces at a surface temperature less than 60 EF nor greater than 90 EF.

g. Application of epoxy-bonded concrete. -

(1) Forms. - Forms shall be used for epoxy-bonded concrete whenever necessary to confine the concrete and shape it to the required lines. The forms shall have sufficient strength to withstand the pressure resulting from placing operations, shall be maintained rigidly in position, and shall be sufficiently tight to prevent loss of mortar from the concrete.

(2) Preparation of epoxy resin. - The epoxy resin is a two-component material which requires combination of components and mixing prior to use. Once mixed, the material has a limited pot life and must be used immediately. The bonding system shall be prepared by adding the curing component to the resin component in the proportions recommended by the manufacturer, followed by thorough mixing. Since the working life of the mixture depends on the temperature (longer at lower temperature, much shorter at higher temperature), the quantity to be mixed at one time shall be applied and topped within approximately 30 minutes. The addition of thinners or diluents to the resin mixture will not be permitted. Both components of class C epoxy shall be at 60 EF prior to use.

(3) Application of epoxy resin bond coat for surface repairs. - Immediately after the epoxy resin is mixed, it shall be applied to the prepared, dry existing concrete at a coverage of not more than 80 square feet per gallon, depending on surface conditions. The area of coverage per gallon of agent depends on the roughness of the surface to be covered and may be considerably less than the maximum specified. The epoxy resin may be applied by any convenient, safe method such as squeegee, brushes, or rollers, which will yield an effective coverage, except that spraying of the materials will be permitted only if an efficient airless spray is used and when the concrete surfaces to receive the agent are 70 EF or warmer, which spray shall be demonstrated as providing an adequate job with minimum overspray prior to approval of its use. If spray application is used, the operator shall wear a compressed air-fed hood, and no other personnel shall be closer than 100 feet if downwind of the operator when spraying is being performed.

Care shall be exercised to confine the epoxy resin to the area being bonded and to avoid contamination of adjacent surfaces. However, the epoxy bond coat shall extend slightly beyond the edges of the repair area.

Steel to be embedded in epoxy-bonded concrete shall be coated with epoxy resin. The steel shall be prepared in accordance with the requirements of section 2 and in the same manner required for preparation of the concrete being repaired. The exposed steel shall be completely coated with epoxy resin at the time it is being applied to the concrete surfaces of the repair area.

The applied epoxy resin film shall be in a fluid condition at the time the concrete is placed, provided that the epoxy resin may be allowed to stiffen to a very tacky condition rather than a fluid condition before concrete is placed on steep sloping or vertical surfaces, in which case special care shall be taken to thoroughly compact the concrete against the stiffening bond coat. In the event that an applied film cures beyond the fluid condition, or a very tacky condition where permitted, before the concrete is placed, a second bond coat shall be applied while the first bond coat is still tacky. If any bond coat has cured beyond the tacky state, it shall be completely removed by sandblasting, and proper cleanup, heating, and drying shall be accomplished, and a new bond coat applied.

(4) Placing and finishing. - Use of epoxy-bonded concrete in repairs requiring forming, such as on steeply sloped or vertical surfaces, will be permitted only when the forming required is such that the bond coat can be applied and the concrete properly placed within the time period necessary to ensure that the applied bond coat will still be fluid, or tacky where permitted.

Immediately after application of the epoxy bond coat, while the epoxy is still fluid, concrete shall be spread evenly to a level slightly above grade and compacted thoroughly by vibrating, tamping, or both. Vibrators shall not be permitted to penetrate through the fresh concrete to the level of the fluid epoxy bond coat. Such vibration can emulsify the epoxy and reduce the bond. Tampers shall be sufficiently heavy for thorough compaction. After being compacted and screeded, the concrete shall be given a wood float or steel trowel finish, as directed. Troweling, if required, shall result in a smooth, dense finish that is free from defects and blemishes. As the concrete continues to harden, the surface shall be given successive trowelings. The final troweling shall be performed after the surface has hardened to such an extent that no cement paste will adhere to the edge of the trowel. The number of trowelings and time at which trowelings are performed shall be subject to approval of the Contracting Officer.

The surfaces of epoxy-bonded concrete repairs shall be finished to the plane of the surfaces adjoining the repair areas. The final finished surfaces shall match the texture of the surfaces adjoining the repair areas.

h. Curing and protection. - The Contractor shall cure and protect all repairs from damage until acceptance by the Government. Concrete shall be protected against freezing for not less than 6 days from time of placement.

As soon as the epoxy-bonded concrete has hardened sufficiently to prevent damage, the surface shall be moistened by spraying lightly with water and then covering with sheet polyethylene, or by applying an approved curing compound, provided that curing compound shall be used for curing concrete whenever there is any possibility that freezing temperatures will prevail during the curing period. Sheet polyethylene, if used, shall be an airtight, nonstaining, waterproof covering which will effectively prevent loss of moisture from the concrete by evaporation. Edges of the polyethylene shall be lapped and sealed. The waterproof covering shall be left in place for not less than 14 days.

If a waterproof covering is used and the concrete is to be subjected to any use that might rupture or otherwise damage the covering during the curing period, the covering shall be protected by a suitable layer of clean wet sand or other cushioning material that will not stain concrete, as approved by the Contracting Officer. Application of curing compound, if used, shall be in accordance with Reclamation's "Specifications for Concrete Curing Compound, M-30." After the curing has been accomplished, the covering, except curing compound if used, and all foreign material shall be removed and disposed of as directed.

3.9 POLYMER CONCRETE SYSTEMS

a. General. - Polymer concrete repair systems for concrete may be either of two types: a methacrylate monomer system, or a vinyl ester resin system. These materials may be used for patches, overlays, grout pads, and embedment of sills, gates, and similar structures in concrete members. Prior approval of the Contracting Officer is required for applications where the repair is exposed to the direct rays of the sun or subjected to rapid temperature changes in excess of 10 EF per hour for more than a 3-hour period. The materials may be supplied as a prepackaged system or as components for a system designed for use as polymer concrete.

The polymer concrete system shall consist of a 100-percent reactive monomer or resin system (no nonreactive diluents or solvents are permitted); an initiator for polymerization of the resin or monomer system, a promoter to activate the initiator; aggregate; and a primer system to be applied to the surface of the concrete to be repaired. The system shall be supplied with or without pigments to approximate the color of concrete, as directed by the Contracting Officer.

b. Submittals. - Before starting work, the Contractor shall submit to the Contracting Officer for approval the following documents:

(1) A safety plan.

(2) A statement of technical qualifications, training, and past experience in handling and applying polymer concrete materials.

(3) A manufacturer's affidavit that states the chemical constituents and proportions of the material, a Materials Data Safety Sheet for each component, the use for which the material is designed, instructions on storage and use of the materials, and typical mechanical and physical properties of the final product.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. -

(1) Monomer and resin systems. -

(a) Methacrylate monomer systems. - The monomer system may be based on either methyl methacrylate monomer or on high molecular weight methacrylate monomer systems. The monomer system shall consist of 100-percent reactive components, and no nonreactive diluents or solvents shall be permitted. The initiator shall be an organic peroxide. The promoter shall be either a cobalt salt or an organic amine compound. Materials shall be used in the proportions recommended by the manufacturer for the temperature conditions at the job site to meet the pot life and curing time requirements of these specifications.

(b) Vinyl ester resin systems. - The vinyl ester resin shall be an elastomer-modified dimethacrylate diglycidyl ether of bisphenol A and shall be Dow Chemical Company Derakane 8084; or equal having the following salient characteristics:

Liquid Resin Properties	
Styrene content	45 percent by weight
Viscosity, Brookfield (cps), 77 EF	1,200
Flash point, cc, (EF)	82
Clear Casting Properties	
Tensile strength, (lb/in^2)	10,000
Tensile modulus (lb/in^2)	430,000
Elongation, percent	10
Flexural strength, (lb/in^2)	16,000
Flexural modulus, (lb/in^2)	420,000
Heat distortion temperature (EF)	170

The initiator shall be an organic peroxide and the promoter shall be cobalt napthenate or cobalt octoate. Materials shall be used in the proportions recommended by the manufacturer for the temperature conditions at the job site to meet the pot life and curing time requirements of these specifications.

(2) Aggregates. -

(a) Prepackaged systems. - Prepackaged systems normally contain a preblended fine aggregate. The use of additional fine aggregate shall not be permitted in these systems unless specifically authorized by the manufacturer. Prepackaged systems that do not contain a preblended fine aggregate shall use a fine aggregate meeting the requirements of subparagraph 3.9.d.(2)(b). Prepackaged polymer concrete systems may be extended by the addition of coarse aggregate. The maximum size of the coarse aggregate shall not exceed the lesser of either one-third of the depth of the repair or 1-1/2 inches. The coarse aggregate shall be composed of hard, dense, clean durable, well-graded rock particles.

(b) Separate component polymer concrete systems. - The aggregate shall be composed of hard, dense, clean, durable, well-graded rock particles. Not more than 2 percent by weight of the fine aggregate shall pass the 75 µm (No. 200) sieve, and the maximum aggregate size shall not be greater than one-third the depth of the repair. The grading shall be based on the following guide:

Nominal size fraction	Aggregate grading percent retained by weight					
9.5 - 19.0 mm (3/8 - 3/4 inch)	--	--	--	--	--	29
4.75 - 9.5 mm (No. 4 - 3/8 inch)	--	--	--	--	29	20
2.36 - 4.75 mm (No. 8 - No. 4)	--	--	--	29	21	16

1.18 - 2.36 mm (No. 16 - No. 8)	--	--	31	21	16	10
600 µm - 1.18 mm (No. 30 - No. 16)	--	31	22	15	10	7
300 - 600 µm (No. 50 - No. 30)	50	23	16	10	7	5
150 - 300 µm (No. 100 - No. 50)	30	16	10	8	4	
*Pan	20	30	21	17	13	9

*NOTE: Pan material shall consist of:
1. Minus 75 µm (No. 200) sieve size ground silica, or
2. Minus 75 µm (No. 200) sieve size crushed hard, dense, durable, clean rock washed free of clay and organic impurities, or
3. A mixture of 1 or 2 above with 50% fly ash.

(3) Coupling agent. - The coupling agent incorporated into the monomer or resin system shall be an organosilane compound, Union Carbide A-174, or equal.

(4) Primer. - The polymer concrete shall be applied to a prepared and primed concrete surface. The primer shall consist of either a methyl methacrylate monomer system, a high molecular weight methacrylate monomer system, or an elastomer-modified vinyl ester resin system (Dow Chemical Company Derakane 8084, or equal). The same monomer or resin system used in the polymer concrete is acceptable as a primer. The polymer concrete shall be applied to a primed surface while the primer is still tacky and has not completely cured to a hard and dry finish, with the exception of methyl methacrylate polymer concrete systems applied to a methyl methacrylate primer system which does not contain cross-linking comonomers which may be applied to a cured and dry primed surface. The primer system shall be formulated according to the manufacturer's instructions to give adequate pot life for the job site temperature conditions for proper application of the polymer concrete.

(5) Polymer concrete properties. - The polymer concrete shall have the following properties:

(a) Curing time of 1 to 3 hours at ambient temperature (substrate and air) of 32 to 100 EF.

(b) Pot life of 15 to 30 minutes at ambient temperatures of 32 to 100 EF.

(c) Compressive strength of at least 7,000 lb/in^2. (ASTM C 39).

(d) Splitting tensile strength of at least 1,000 lb/in^2. (ASTM C 496).

(e) Linear shrinkage, less than 0.05%.

(f) Bond strength to concrete - at least equal to the splitting tensile strength of the base concrete.

e. Safety. - All work shall be performed in accordance with requirements of paragraph 1.6 and these specifications. The Contractor shall also:

(1) Hold a safety meeting at the job site conducted by an industrial hygienist or by a technically qualified professional staff member to acquaint and instruct all workers and supervisors on the job in the proper care and handling of the polymer concrete materials as specified by the manufacturer of the polymer concrete, safety precautions to be observed, personal protective gear, and protection of the environment.

(2) Require all workers, supervisors, inspectors, visitors, and other people at the job site to wear personal protective gear as directed by the Contracting Officer.

(3) Ensure that the polymer concrete materials are stored, handled, and applied in the manner specified by the manufacturer. In addition:

(a) Storage. - polymer concrete materials shall be stored in the shipping containers in a well-ventilated area and out of the direct rays of the sun. The storage temperature shall not exceed 80 EF (27 EC). Materials shall not be stored longer than 3 months.

(b) Mixing and application. - No smoking, flame, or other ignition sources shall be permitted during mixing and application. Type B or type ABC fire extinguishers shall be provided at the mixing and application sites. Electrical equipment in contact with the polymer concrete should be grounded for safe discharge of static electricity.
(c) Handling. - Workers shall be provided and required to wear rubber boots, disposable protective clothing, splash-type safety goggles, rubber gloves, and organic vapor respirators as directed by the Contracting Officer. A heated eye wash capable of sustaining a 15-minute stream of clean, room temperature water shall be provided at the mixer and at the application site. Materials coming into direct contact with the skin shall be immediately removed using soap and water.

(4) Prevent the contamination of soil or water at the job site by liquid components.

(5) Dispose of liquid components and excess materials at the job site by combining the materials in the same manner and procedure used for mixing polymer concrete, placing the mixed materials in an open container, and allowing the material to harden. Hardened polymer concrete is nonpolluting and may be disposed of as a solid nonhazardous waste.

f. Concrete preparation. - In addition to the requirements of section 2, the concrete surface shall be dry and primed with an approved primer.

The primer and the polymer concrete shall not be applied until the surface preparation meets the approval of the Contracting Officer. The dryness of the surface shall be determined by taping a sheet of transparent polyethylene sheeting to the surface and exposing it to the full rays of the sun for at least 4 hours and observing the interior surface of the polyethylene sheeting for the occurrence of condensed moisture. As an alternative method, a calibrated moisture meter which meets the approval of the Contracting Officer may be used to determine the dryness of the surface.

g. Preparation and application requirements. -

(1) Initiator and promoter. - The initiator and promoter shall be prebatched and packaged separately from each other in a manner so that the two components cannot be combined until the time of the concrete mixing operation. The promoter shall be combined with the monomer or resin system prior to the addition of the initiator. <u>UNDER NO CIRCUMSTANCES SHALL THE INITIATOR BE ADDED TO OR DIRECTLY CONTACT THE PROMOTER. THE DIRECT COMBINATION OF PROMOTER AND INITIATOR WILL RESULT IN AN EXTREMELY VIOLENT AND EXPLOSIVE REACTION.</u>

(2) Sequence of addition and combination of materials at the mixer. - The polymer concrete materials shall be combined in the sequence and manner specified by the manufacturer.

(3) Mixing of polymer concrete. - The polymer concrete shall be mixed in a paddle-type power mixer, a rotating drum-type power mixer, or other type of power equipment approved by the Contracting Officer. Polymer concrete materials shall be mixed according to the recommendations of the manufacturer of the polymer concrete materials for at least 3 minutes.

(4) Removal of polymer concrete from the mixer. - The polymer concrete shall be removed from the mixer immediately after mixing.

(5) Appropriate forms shall be used for polymer concrete whenever necessary to confine the polymer concrete and shape it to required lines. The surfaces of the forms shall be coated with a release agent that will effectively prevent sticking without damage to the polymer concrete surfaces.

3.10 THIN POLYMER CONCRETE OVERLAY

a. General. - Thin polymer concrete overlay shall consist of one coat of primer and one or more coats of sealant as directed by the Contracting Officer.

The coat of primer shall consist of vinyl ester resin, initiator, and promoter. Each coat of sealant shall consist of the same materials as in the primer, but with the addition of silica filler, titanium dioxide pigment, and carbon black pigment.

b. Submittals. - The Contractor shall, before starting work, provide a manufacturer's affidavit which indicates the chemical constituents of the material by proportion. The chemical constituents shall correspond to the requirement of subparagraph 3.10.d.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications.

The vinyl ester resin shall be stored in the shipping containers and kept in the shade, well ventilated, and out of direct sunlight. The recommended storage temperature is 50 to 75 EF. Resin shall not reach 80 EF or higher, as it will start to gel. The resin has a storage life of about 3 months. During storage, the resin shall not come in contact with copper, brass, zinc, or rust, as discoloration, polymerization, or interference with normal cure conditions can occur. Resin shall also not contact rubber, as resin is a solvent for rubber.

Styrene monomer, which is a component of vinyl ester resin, is flammable and forms explosive mixtures in the air; however, it is not sufficiently flammable to be listed as a "flammable liquid" under Interstate Commerce Commission definitions (flash point at or below 80 EF). The explosive limits are 1.1 to 6.1 percent volume in air.

The Contracting Officer will not allow the use of vinyl ester resin if it has already polymerized, gelled, discolored, or will not cure under normal conditions. Substandard materials shall be replaced at the expense of the Contractor.

d. Materials. -

(1) Vinyl ester. - The vinyl ester resin material shall be Dow Derakane 8084 elastomer-modified vinyl ester resin, manufactured by Dow Chemical Co., 2800 Mitchell Drive, Walnut Creek CA 94596; or equal. It shall meet the requirements of 3.9.d.(1)(b).

(2) Initiator. - The initiator shall be cuemene hydroperoxide - 78 percent as manufactured by: Lucidol Division, Penwalt Corp., 1740 Military Road, Buffalo NY 14240; Reichold Chemicals, Inc., 107 South Motor Avenue, Azusa CA 91706; Witco Chemicals, U.S. Peroxygen Division, 850 Morton Avenue, Richmond CA 94804; or equal.

(3) Promoter. - The promoter shall be cobalt napthenate; 6 percent.

(4) Filler. - The filler shall be ground silica, minus 45 µm (No. 355) sieve size as manufactured by: Ottawa Silica Co., Ottawa, Illinois; VWR Scientific (Silco Seal 395 Ground Silica), PO Box 3200, San Francisco CA 94119; or equal.

(5) Pigment for opaqueness. - Two pigments shall be used and they shall be:

(a) Titanium dioxide powder as manufactured by: VWR Scientific, PO Box 3200, San Francisco CA 94119; MCB Manufacturing Chemist, Inc., 470 Valley Drive, Brisband CA 94005; or equal.

(b) Carbon lamp black or bone black powder. - (Do <u>not</u> use activated carbon)

e. Safety. - All work shall be performed in accordance with paragraph 1.6 and these specifications. No smoking, flame, or other ignition source shall be present during mixing and the application procedures. Fire extinguishers (types B or ABC) shall be provided. Equipment contacting resins shall be grounded for safe discharge of static electricity. Tools used shall be the non-sparking, special alloy type.

Workers shall be provided with rubber boots, rubber gloves, protective clothing, safety goggles or face shields, and organic vapor respirators. It is important to avoid inhalation of vapors and direct eye or skin contact. Eyewash facility shall be available which will provide a clean, room temperature flushing stream for a minimum of 15 minutes. Contaminated clothing shall be discarded immediately. Proper tools and facilities to quickly remove spills shall be at the worksite.

Personnel shall follow manufacturer's recommendations for safe handling of vinyl ester resin and all additives.

CUEMENE HYDROPEROXIDE INITIATOR SHALL NEVER BE ADDED DIRECTLY TO COBALT NAPTHENATE PROMOTER OR AN EXTREMELY VIOLENT AND EXPLOSIVE REACTION WILL OCCUR.

f. Concrete preparation. - Concrete surfaces designated to receive the thin polymer concrete overlay shall be prepared in accordance with section 2. The minimum preparation shall consist of wet sandblasting or water blasting the concrete to a clean, sound surface condition followed by drying.

g. Application of the thin polymer concrete overlay. -

(1) Coverage. - An average coverage rate of 50 to 75 square feet per gallon of applied material per coat over the entire surface is anticipated for this work. The surface texture of the concrete may affect this coverage rate.

(2) Mixing proportion. -

(a) Primer: 5.0 gallons vinyl ester resin
0.60 pound initiator
0.25 pound promoter

(b) Sealant: 5.0 gallons vinyl ester resin
1.35 pounds initiator
0.27 pounds promoter
40.0 pounds filler
4.0 pounds titanium dioxide pigment
0.02 pound carbon lamp black pigment

(3) Variations. - The proportions of cobalt napthenate promoter and cuemene hydroperoxide initiator were selected to give a 2- to 4-hour pot life at a temperature of about 70 EF. The rate of the polymerization reaction also depends on temperature - in colder weather the reaction will be slower, and in hot weather or in sunshine, the reaction will proceed faster. The temperature effects can be compensated for, to a certain extent, by increasing the total amount of initiator plus promoter in cold weather and decreasing the amount in hot weather.

Great care shall be exercised in proportioning the titanium dioxide and the carbon black to ensure exact color between batches of sealant layer.

The Contracting Officer may require variations from the proportions and quantities specified above and trial mixtures.

At no additional cost to the Government the Contracting Officer may require two trial mixtures utilizing a total of 5 gallons of vinyl ester resin with a proportional amount of other materials as indicated in subparagraph 3.10.g.(2). The Contractor shall supply, mix, and apply the trial polymer overlay where directed and in a manner as indicated by these specifications. The Contracting Officer shall be given 12 hours' notice before a trial mix is applied.

(4) Mixing. - The filler, pigments, and cobalt napthenate promoter shall be mixed with vinyl ester resin in a paddle-type or rotating drum power mixer in advance of the application. Mixtures shall be prepared in maximum volumes of 5 gallons of resin per mixed batch.

The Contractor shall mix the required constituents, with the exception of the cuemene hydroperoxide, to the satisfaction of the Contracting Officer. The sealant material will then be required to set for 45 to 90 minutes for the filler and pigment to become thoroughly wetted by the vinyl ester resin. Just prior to use, the cuemene hydroperoxide initiator shall then be added and the sealant mixture mixed again to the Contracting Officer's satisfaction. CUEMENE HYDROPEROXIDE INITIATOR AND COBALT NAPTHENATE PROMOTOR SHALL NEVER BE ADDED TOGETHER DIRECTLY, OR AN INSTANTANEOUS AND VIOLENTLY EXPLOSIVE REACTION COULD OCCUR. For the primer, the setting period may be omitted, but the initiator must still be added after the first mixing of the promoter, then mixed again.

(5) Application. - The primer shall uniformly and completely cover the surface by being spread and scrubbed into the concrete surface with a paint roller, brush, or push broom. Discontinuities and puddles shall be eliminated by vigorous scrubbing action. The application rate of primer is expected to be 1 gallon per 50 to 75 square feet of surface area, but may vary due to texture of the prepared surface.

The pigmented sealant layers of the overlay material shall be applied not less than 4 and no greater than 24 hours after the application of the primer or succeeding sealant layer. The primer layer may not have completely cured during this time period. The sealant shall be applied to dry, primed surfaces, and provisions shall be taken to prevent wetting of the surfaces from rain or leakage and seepage of water. The sealant layers shall also be applied with a paint roller, brush, or push broom. The application rate of the sealant is expected to be 1 gallon per 50 to 75 square feet of surface area.

The primer and sealant layers shall be spread evenly and uniformly over the surface.

3.11 RESIN INJECTION

a. General. - When hardened concrete is cracked in depth or when hollow plane delaminations or open joints exist in hardened concrete and when structural integrity or watertightness must be restored for the structure to be serviceable, resin injection shall be used for repair, as directed.

However, since not all cracked, delaminated, or jointed concrete can be restored to serviceable condition by resin injection, resin injection repairs shall be made only as directed by the Contracting Officer.

Two basic types of injection resin are used to repair concrete:

(1) Epoxy resins are used to rebond cracked concrete and to restore structural soundness. Epoxy resins may also be used to eliminate water leakage from concrete cracks or joints, provided that cracks to be injected with epoxy resin are stationary. Cracks that are actively leaking water and that cannot be protected from uncontrolled water

inflow shall not be injected with epoxy resin. Cracks to be injected with epoxy resin shall be between 0.005 inch and 0.25 inch in width.

(2) Hydrophilic polyurethane resin is used to eliminate or reduce water leakage from concrete cracks and joints and can be used to inject cracks subject to some degree of movement. Hydrophilic polyurethane resin shall not be used to inject concrete cracks or joints when restoration of structural bond is desired. Cracks to be injected with polyurethane resin shall be 0.005 inch in width or greater.

Other types of injection resin are available for nonstandard or specialized repair applications. Use of these materials shall require specific approval of the Contracting Officer.

b. Submittals. - The Contractor shall provide the Contracting Officer with evidence that the Contractor is qualified to perform resin injection repairs. The data shall show that the Contractor has a minimum of 3 years of experience in performing resin injection work similar to that detailed in the drawings and specifications.

The Contractor shall submit a list of 5 projects in which resin injection was successfully completed. The list shall contain the following information for each project:

(1) Project name and location.

(2) Owner of project.

(3) Brief description of work.

(4) Date of completion of resin injection work.

If the repair work is performed by the Contractor's personnel under the supervision of the manufacturer's representative, the data shall show that the resin manufacturer has a minimum of 5 years' experience providing resin materials similar to those specified.

Manufacturer's brochures, technical data sheets, Material Safety Data Sheets, and any other information describing the polyurethane resin, the proper formulation to achieve the required tensile strength, bond strength, and elongation of the cured resin mixture, and recommended injection procedures shall be submitted to the Contracting Officer for approval at least 30 days prior to commencement of crack repairing operations.

The Contractor shall furnish the Contracting Officer a manufacturer's certification of conformance of the epoxy or polyurethane resin system with these specifications. The certification shall identify the Reclamation solicitation/specifications number(s) under which the resin is to be used and shall include the quantity represented, the batch numbers of the resin, and the manufacturer's results of tests performed on the resin system.

The Contractor shall submit a detailed proposal for epoxy injection repair to the Contracting Officer for approval. The approval will be based on the degree of conformance of the proposal with procedures contained in Reclamation's Concrete Manual, chapter 7, Eighth Edition, revised reprint, and the report of ACI Committee 503, section 7.2.5, "Use of Epoxy Compounds with Concrete."

The Contractor shall submit a detailed proposal for polyurethane resin injection repair to the Contracting Officer for approval. The approval will be based on the degree of conformance to the basic steps of polyurethane resin injection and on the Contracting Officer's judgment of the technical feasibility of the Contractor's proposal.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications. The repair work may be performed by the Contractor or by the Contractor's personnel under the supervision of the resin manufacturer's representative. If the Contractor performs the repair work, the Contractor shall provide a full-time, onsite supervisor throughout the duration of the resin injection work.

If the repair work is performed by the Contractor's personnel under the supervision of the resin manufacturer's representative the Contractor shall have the resin manufacturer provide a representative who will train the Contractor's personnel on the proper techniques of injecting resin with an injection system approved by the manufacturer. Also, the Contractor shall provide a full-time, onsite, manufacturer-certified injection supervisor throughout the duration of the resin injection work.

d. Materials. -

(1) Epoxy resin. - Epoxy resin for injection shall meet the requirements of specification ASTM C-881 for a type I, grade 1 epoxy system. The class of the system shall be appropriate for the temperature of the application.

(2) Polyurethane resin. - The polyurethane resin system for injection into cracked concrete shall be a two-part system composed of 100 percent hydrophilic polyurethane resin and water. The polyurethane resin, when mixed with water, shall be capable of forming either a flexible closed-cell foam or a cured gel dependent upon the water-to-resin mixing ratio. The amount of water mixed with the polyurethane resin shall be such that the cured material meets the following physical properties:

(a) Minimum tensile strength -- 20 pounds per square inch.

(b) Bond to concrete (wet) -- greater than 20 pounds per square inch.

(c) Minimum elongation -- 400 percent.

The injection of pure polyurethane resin, not mixed with water, shall not be allowed.

e. Safety. - All work shall be performed in accordance with paragraph 1.6 and these specifications.

(1) Epoxy resins. - Certain additional safety precautions shall be employed when using uncured epoxy materials. Skin contact with uncured epoxy shall be avoided. Protective clothing, including rubber or plastic gloves, shall be worn by all persons handling epoxy materials. All exposed skin areas that may come in contact with the material shall be protected with a protective barrier cream formulated for that purpose. Adequate ventilation shall be provided and maintained at all times during use of epoxy and epoxy solvents. Fans used for ventilating shall be explosion proof. If necessary, respirators that filter organic fumes and mists shall be worn. All

epoxy-contaminated materials such as wipes, empty containers, and waste material shall be continually disposed of in containers which are protected from spillage. Epoxy spillage shall be immediately and thoroughly cleaned up. Appropriate solvents may be used to clean tools and spray guns, but in no case shall the solvents be incorporated in any epoxy resin or in the placing operation. Solvents shall not be used to remove epoxy materials from skin. Only soap, water, and rags shall be used for this purpose.

All tools shall be completely dried after cleaning and before reuse.

(2) Polyurethane resins. - Polyurethane injection resin systems contain either toluene diisocyanate or methylene dephenyl diisocyanate. Both isocyanates can create risks if safe handling procedures are not followed. The principal hazards arise from isocyanate vapor, which will irritate the membranes of the nose, throat, lungs, and eyes. Adequate ventilation is required to prevent vapor concentrations from approaching the Threshold Limit Value (TLV). Protective clothing, including rubber or plastic gloves and protective glasses, shall be worn by all persons handling polyurethane resins. If necessary, respirators that filter isocyanate vapors and mists shall also be worn. Monomeric urethane resins react with water to produce polyurethane and carbon dioxide gas. If this reaction occurs inside a closed container, excessive pressures can develop that may rupture the container. Care must be taken to prevent contamination of monomeric urethane resin with water.

Polyurethane resin spillage shall be immediately and thoroughly cleaned up. Spilled polyurethane resin can be absorbed in sand and removed for burial.

(3) Cleanup and disposal of injection resin. - All materials, tools, and containers contaminated with injection resin, surface sealers, or other contaminants shall be removed from the site for disposal in accordance with appropriate local or Federal regulations.

f. Concrete preparation. - The concrete surface to be repaired by resin injection shall be thoroughly cleaned of all deteriorated concrete, efflorescence, and all other loose material. The area to be injected shall then be thoroughly inspected and an injection port drilling and pumping pattern established.

Upon completion of resin injection, all excess material shall be removed from the exterior surfaces of the concrete. The final finished surfaces shall match the texture of the surfaces adjoining the repair areas.

g. Application of resin injection repairs to concrete. -

(1) Epoxy resin injection repair. - The process used for epoxy injection shall fill the entire crack or hollow plane delamination with liquid epoxy resin system and shall contain the resin system in the crack until it has hardened. The Contractor shall be responsible for drilling and removing three, a minimum of 2-inch-diameter cores from the injected concrete at locations determined by the Contracting Officer to determine the completeness of the injection repair. Injection shall be considered complete if more than 90 percent of the void is filled with hardened epoxy. If injection is not complete, reinjection and additional cores may be required at the direction of the Contracting Officer at no additional cost to the Government.

Epoxy injection repair methods shall be in accordance with the approved detailed proposal for epoxy injection repair and shall be adjusted to fit the repair situations encountered.

(2) Hydrophilic polyurethane resin injection repairs. - The process used for polyurethane injection of cracks or joints to reduce water leakage shall consist of the following basic steps:

(a) Intercept the water flow paths with valved drains installed into the concrete to control the leakage.

(b) Install injection ports by drilling holes designed to intersect the cracks at depth below the concrete surface. The maximum spacing of injection ports shall not exceed 60 inches, and closer spacing of ports may be required.

(c) All injection holes shall be flushed with clean water to remove drilling dust and loose debris and to clean the intersected crack line. Each drill hole shall be water tested at the resin injection pressure to determine if the crack intersection is open. Polyurethane resin shall not be pumped into a drill hole that refuses to take water at the resin injection pressure.

(d) Inject polyurethane resin system into cracks or joints at the minimum pressure required to obtain the desired travel, filling, and sealing. The mix water to resin ratio shall be 1:1 unless otherwise approved by the Contracting Officer. The Contractor should anticipate the necessity to provide a surface seal for the crack or joint to contain the injection resin. It may also be necessary to inject the crack or joint in an intermittent manner to achieve filling and sealing. Injection shall be by the method of split spacing unless otherwise approved by the Contracting Officer. Primary holes shall be drilled and injected on centers not exceeding 10 feet. Secondary holes, half way between the primary holes, will then be drilled and injected. If resin take occurs in the secondary holes, a series of tertiary holes, half way between the secondary and primary holes, shall then be drilled and injected. All holes shall be injected to absolute refusal.

(e) Remove drains, injection ports, and excess polyurethane upon completion of resin cure.

This process shall entirely stop the water leakage to a dust dry condition or as directed by the Contracting Officer.

The pump used to inject the polyurethane resin system shall be a two-component positive-displacement-type pump with static mixing head and pressure regulation necessary to control injection pressures while pumping low volumes. The equipment will be subject to approval by the Contracting Officer. The use of single component pumps and/or the injection of pure water followed by injection of pure resin will not be approved.

Polyurethane resin injection methods shall be in accordance with the approved, detailed proposal for injection repair and shall be adjusted to fit the repair situations encountered.

3.12 HIGH MOLUCULAR WEIGHT METHACRYLIC SEALING COMPOUND

a. General. - A concrete sealing compound is defined as a liquid that is applied to the surface of hardened concrete to prevent or decrease the penetration of liquid or gaseous media, such as water, aggressive solutions, and carbon dioxide, during the service exposure, preferably after initial drying to facilitate its absorption into voids and cracks.

The sealing of concrete surfaces with a high molecular weight methacrylic monomer-catalyst system and sand shall be in accordance with these specifications. Other types of concrete sealing compounds may be used by the Contractor only when approved by the Contracting Officer.

The high molecular weight methacrylic sealing compound shall not be used to seal concrete subject to frequent or permanent immersion in water; nor shall it be used on concrete surfaces exposed to high abrasion forces.

b. Submittals. - The Contractor shall provide the Contracting Officer a table showing preparation of initiator and promoter to be added to the monomer to achieve the cure time requirements based on concrete surface temperature. The temperature of the surface to be treated shall range from 45 to 100 EF. If it is desired to work outside these temperature ranges, approval of the Contracting Officer is required, and the monomer manufacturer should be consulted for technical advice.

A MSDS shall be furnished to the Contracting Officer prior to shipment of material with information pertaining to the safe practices for storage, handling and disposal of the materials and their explosive and flammable characteristics, health hazards, and the manufacturer's recommended fire fighting techniques. The MSDS shall be posted at all storage areas and at the job site.

The Contractor shall furnish, for approval, a detailed written description of the methods the Contractor plans to use for clean up of all spills and residue in open containers. See subparagraph 3.12.g.(4).

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. -

(1) High molecular weight methacrylic monomer. - The monomer shall be a high molecular weight or substituted methacrylate that conforms to the following properties:

(a) Vapor pressure Less than 1.0 mm HG @ 77 EF (ASTM D 323)

(b) Flash point Greater than 200 EF (Pensky-Martens CC)

(c) Density Greater than 8.4 lb/gal at 77 EF (ASTM D 2849)

(d) Viscosity 12 ± 4 cps (Brookfield No. 1 Spindle 60 rpm, at 73 EF)

(e) Index of refraction 1.470 ± 0.002

(f) Boiling point @ 1 mm Hg, degrees F 158

(g) Shrinkage on cure -less than- 11%

(h) Glass transition temperature (DSC), degrees F. 135 EF (ASTM D 3418)

(i) Curing time (100 g mass) Greater than 40 minutes at 77 EF, with 4% cuemene hydroperoxide (ASTM D 2471)

(j) Bond strength greater than 1,500 lb/in^2 (ASTM C 882)

(k) No unreactive solvents or diluents shall be permitted in the monomer system.

(2) Initiator-promoter system. -

(a) Initiator Cuemene hydro peroxide - 78 percent

(b) Promoter Cobalt Napthenate - 6 percent

The initiator/promoter system shall be capable of providing a surface cure time of not less than 40 minutes nor more than 3 hours at the surface temperature of the concrete during application. The initiator/promoter system shall be such that the gel time may be adjusted to compensate for changes in temperature that may occur throughout the treatment application.

(3) Sand. - The sand shall be clean, dry, and free of organic materials, silt, and clay. Except as otherwise approved by the Contracting Officer, the sand shall conform to the following grading:

U.S. standard sieve size	Percent passing
4.75 mm (No. 4)	100
2.36 mm (No. 8)	90-10
850 μm (No. 20)	5-10
300 μm (No. 50)	0-10

This grading is intended to allow the use of commercially available silica sands of No. 8/20 or No. 10/20.

e. Safety. - All work shall be performed in accordance with the requirements of paragraph 1.6 and these specifications. The materials shall be stored, handled, and applied in accordance with the manufacturer's recommendations. Storage of all materials shall be in the original shipping containers and as specified in this paragraph.

<u>INITIATORS AND PROMOTERS SHALL BE STORED SEPARATELY SINCE COMBINATION CAN RESULT IN A VIOLENT REACTION OR EXPLOSION.</u>

Personnel exposed to monomer, initiator, or promoter, or their vapors shall use minimum protective equipment as follows: safety eye glasses, impervious gloves and aprons, and rubber boots as required. As determined by the Contracting Officer, personnel may be required to use full-face protective shields, self-contained respiratory equipment, or both. All personnel handling the monomer or catalysts shall be thoroughly trained in their safe use in accordance with the manufacturer's recommendations.

Unsafe handling practices will be sufficient cause to discontinue work until the hazardous procedures are corrected. The handling and use of the monomer and catalysts shall in all cases comply with the requirements of applicable Federal, State, and local safety requirements and ordinances.

The Contractor shall provide an eye wash and water washing facility for use in the event of accidental splashing of the monomer or catalysts on the workers. Eyewash facility shall be capable of providing a clean, room temperature flushing stream for a minimum of 15 minutes. All sources of sparks or flame must be removed from areas used for storage and handling. In these areas storage and mixing vessels shall be provided with electrical grounds to prevent static sparks.

Mixing and transfer equipment shall be explosion proof, and sufficient ventilation shall be provided to prevent the formation of explosive sealant/air mixtures. In accordance with applicable safety regulations, warning signs, such as "No Smoking" signs, shall be posted. In public areas, care shall be taken to eliminate sources of sparks or flame when the monomer system is present. Particular attention should be given to removal of welding operations, posting of "No Smoking" signs, and to traffic control to eliminate accidental fires from these sources. Visitors at the job site should be warned of the potential hazards and provided with applicable safety equipment. The Contractor shall also place an adequate number of 4-A:60B:C fire extinguishers on the job, so that no portion of the monomer system application is conducted farther than 100 feet from the nearest fire extinguisher.

f. Concrete preparation. - The concrete surfaces to be treated shall be clean, dry, and physically sound. All deteriorated concrete shall be removed in accordance with paragraph 2.1 to obtain a physically sound surface for treatment. The Contractor shall perform all work required to bring the surfaces to this condition.

Concrete surfaces shall then be prepared by power sweeping and by blowing with high-pressure air to remove all dirt and foreign material from the surface and from all cracks. Contaminants, such as asphalt and heavy oil and rubber stains, shall be removed, at the discretion of the Contracting Officer, by scraping and cleaning with solvents. Well-bonded surface contaminants and existing painted surfaces shall be removed by wet sandblasting. High-pressure water blasting will be permitted only if it can be demonstrated to the satisfaction of the Contracting Officer that the concrete surface and cracks can be completely dried prior to the application of the polymer treatment.

g. Application. - The methacrylic concrete sealing compound shall be mixed, applied to the prepared concrete surface, and cured in accordance with these specifications.

(1) Mixing of materials. - The monomer shall be mixed with initiator and promoter in the following proportions (proportions may be adjusted by the Contracting Officer to give a satisfactory pot life based on concrete surface temperatures and recommendations of the monomer system manufacturer):

		Parts by weight
(a)	Substituted Methacrylate Monomer	100
(b)	Cuemene Hydroperoxide (78%)	4.0

(c) Cobalt Napthenate (6%) 2.0

<u>DO NOT MIX COBALT NAPTHENATE DIRECTLY WITH CUEMENE HYDROPEROXIDE AS THIS WILL PRODUCE AN EXTREMELY VIOLENT AND EXPLOSIVE CHEMICAL REACTION.</u>

The cobalt napthenate and cuemene hydroperoxide shall be mixed with the substituted methacrylate monomer in separate steps; i.e., first add and mix cobalt napthenate with the substituted methacrylate monomer, and then add and mix the cuemene hydroperoxide with the cobalt napthenate/ methacrylate monomer mixture.

The materials shall not be premixed. The monomer system shall be applied to the concrete surface within 5 minutes after mixing the cuemene hydroperoxide with the cobalt napthenate/substituted methacrylate monomer mixture.

For manual application, the quantity of monomer system mixed shall be limited to 5 gallons at a time. A significant increase in viscosity or change in gel time prior to application shall be cause for rejection.

Machine mixing and application of the methacrylic sealing compound may also be performed by using a two-part monomer system utilizing a promoted monomer for one part and an initiated monomer for the other part. Adequate mixing shall be done to achieve a uniform blend of the two parts.

The use of machine mixing and application requires approval by the Contracting Officer and treatment of a 10- by 50-foot test site to demonstrate that the equipment is working properly and capable of providing a uniform monomer mixture.

(2) Application of sealing compound. - Prepared surfaces shall be protected from rain and moisture. Surfaces shall be treated with sealing compound within 24 hours after surface preparation is completed. The surface shall be allowed to dry thoroughly for a minimum of 48 hours before treatment. At the discretion of the Contracting Officer, the following test shall be made to determine if the concrete surface is sufficiently dry to proceed with the polymer treatment. A 2-foot-square piece of clear polyethylene sheeting shall be taped to the surface of the concrete and allowed to remain there for a minimum of 2 hours exposed to sunlight. Moisture condensation on the inside surface of the polyethylene sheeting shall be considered as evidence that the concrete surface is not sufficiently dry, and an additional period for drying will be required before proceeding with the polymer treatment. Additional tests may be required, at the discretion of the Contracting Officer.

The monomer system shall be applied to the concrete surfaces during nighttime and early morning hours as directed by the Contracting Officer and with concrete temperatures between 45 and 85 EF. Monomer application will not be permitted in the direct rays of the sun as this may cause a premature curing of the system.

The concrete surfaces shall be treated with monomer at an application rate of 75 to 100 square feet per gallon. The concrete surfaces shall be flooded with the monomer mixture, allowing full penetration of the concrete and filling all cracks, and brushed with a stiff bristle broom. Puddles of excess monomer shall be removed by the Contractor.

The sealing compound may also be spray-applied by machine using a two-part mixing procedure described in subparagraph 3.12.g.(1). The pressure at the spray nozzle shall not be great enough to cause monomer mist to drift more than 2 feet beyond the nozzle. Compressed air shall not be used to produce the spray.

(3) Application of sand and curing. - Within 15 to 20 minutes after application of the methacrylic sealing compound, and before significant gelling has occurred, the entire treated area of concrete shall be covered by sand broadcast to achieve a uniform coverage of 0.25 to 0.50 pound per square yard. This sand shall be left on the concrete surface until the sealing compound has cured to a tack-free condition. Any excess sand, not bonded to the concrete, shall then be removed by the Contractor. Sand shall not be applied to vertical surfaces that have been treated with methacrylic sealing compound.

Treated areas shall be protected and not put back into service for 24 hours after treatment to allow the sealing compound to fully cure.

(4) Cleanup. - The Contractor shall keep the mixing equipment and tools clean during the course of the treatment, using a suitable solvent such as acetone or methyl ketone (both flammable), or 1,1,1,-trichloroethane (nonflammable). Soap and water are also satisfactory for cleanup of fresh monomer from the tools. The Contractor shall quickly clean up all spills by a method previously approved by the Contracting Officer.

After the repair work is completed, the residue in the open containers of cuemene hydroperoxide and cobalt napthenate shall be safely destroyed by using some of the excess monomer resin to wash out the catalyst containers and then allow it to cure before disposal or by other methods recommended by the manufacturers and approved by the Contracting Officer.

3.13 SURFACE IMPREGNATION

a. General. - These specifications present the requirements for impregnating concrete with a methyl methacrylate based monomer-catalyst system followed by in situ polymerization of the monomer by heat.

b. Submittals. -

(1) The Contractor shall provide the Contracting Officer with the manufacturer's certifications that the monomers and catalyst meet these specifications. Representative samples of the monomer system components, or of the combined monomer system if purchased premixed, shall be delivered to the Contracting Officer at least 30 days prior to use. At the Contracting Officer's option, these samples will be tested to determine specifications compliance.

(2) At least 30 days prior to beginning the concrete impregnation process, the Contractor shall deliver to the Contracting Officer a written report describing the Contractor's planned treatment procedures. Included in this report shall be a detailed description of the drying, impregnation, monomer mixing and storage, polymerization and quality control procedures, facilities, and equipment the Contractor intends to use to treat the concrete. The Contracting Officer will review this report and approve or disapprove the plan within 30 days of the date of receipt. In no event shall the Contractor proceed with the surface impregnation treatment until

approval of the Contractor's procedures, materials, and equipment has been received.

(3) During the drying, cooling, impregnation, and polymerization cycles, the Contractor shall obtain and supply to the Contracting Officer concrete temperature data accurate to ±5 EF from at least nine points uniformly spaced on the surface of each treatment area and from at least one point 1 inch below the concrete surface at the approximate center of each treated area.

These data shall be in the form of a continuous record or periodic readings recorded at 1-hour intervals. The technique and equipment used to obtain the temperature data required in subparagraph 3.13.g.(1) shall be described in the written procedures report required above and subject to the Contracting Officer's approval.

(4) The Contractor shall maintain and supply to the Contracting Officer monomer and catalyst records listing the dates of manufacture, storage temperatures, date of use and application rates, and quantities as applied to the concrete.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications. Representative material samples submitted by the Contractor, as specified in subparagraph 3.13.b.(1) will be tested, at the Contracting Officer's option.

d. Materials. -

(1) Monomer system. - The monomer system shall be composed of 95 percent by weight methyl methacrylate (MMA) and 5 percent by weight trimethlolpropane trimethacrylate (TMPTMA). A polymerization catalyst, 2,2-azobis-(2,4-dimethylvaleronitrile), shall be added to this monomer system at the rate of 1 part catalyst to 200 parts monomer by weight, or as directed by the Contracting Officer.

(a) MMA. - MMA shall meet the following requirements:

Formula	$CH_2=C(CH_3)C00CH_3$
Inhibitor	25 parts per million hydroquinone (HQ)
Molecular weight	100
Assay (Gas Chromatography) %	99.8 min
Density	7.83 lb/gal (0.938 kg/L)
Boiling	212 EF (100 EC)
Flash point (Tag, ASTM D 1310)	55 EF (13 EC)

(b) TMPTMA. - TMPTMA shall meet the following requirements:

Formula	$(CH_2=CH_3\ COOCH_2)_3CCH_2CH_3$
Inhibitor	100 parts per million hydroquinone (HQ)

Assay, %	95.0 min
Density	8.82 lb/gal (1.058 kg/L)
Flash point	Greater than 300 EF (149 EC)

(c) The polymerization catalyst shall be 2,2-azobis-(2,4-dimethyl-valeronitrile). Empirical formula: $C_{14}H_{24}N_4$.

Monomer system components shall be used within 6 months after manufacture.

(2) Sand. - The impregnation sand shall be composed of clean, hard, dense, low-absorptive particles that will pass a 1.18-mm (No. 16) sieve, but with not more than 5 percent passing a 150 µm (No. 100) sieve.

e. Safety. - All work shall be performed in accordance with paragraph 1.6 and these specifications. Because of the hazards associated with improper use and handling of the monomer and catalyst, the following additional safety requirements shall be adhered to during the surface impregnation process.

Personnel working with the monomers or catalyst shall be provided with and use safety eyeglasses or goggles, impervious gloves, aprons, and boots. Normally, in an outdoor monomer application, respiratory equipment will not be necessary. In storage and mixing operations, however, accidental spills or equipment failures may result in hazardous vapor concentrations requiring self-contained respiratory equipment for personnel protection. The Contractor shall provide a field eye wash and water washing facility for use in the event of an accidental splash of monomer on the workers. Eye wash facility shall be capable of providing a clean, room temperature flushing stream for a minimum of 15 minutes.

All sources of sparks or flame shall be removed from areas for monomer storage and handling. In these areas monomer storage and mixing vessels shall be provided with electrical grounds to prevent static sparks. Mixing and transfer equipment and motors shall be explosion proof, and sufficient ventilation shall be provided to prevent the formation of explosive monomer vapor-air mixtures. In accordance with applicable safety regulations, warning signs such as "No Smoking" regulations shall be posted. At the construction site, care shall be taken to eliminate sources of sparks or flame when monomer is present. Particular attention shall be given to removal of welding operations, posting of "No Smoking" signs, and to traffic control to eliminate accidental fires from these sources. Visitors at the job site shall be warned of the potential hazards and provided with applicable safety equipment.

Catalyzed monomer not used within 4 hours of catalyst addition shall be stored in an explosion proof storage facility at a maximum storage temperature of 0 EF until it can be used or destroyed as approved by the Contracting Officer. Storage of catalyzed monomer for periods longer than 2 days will not be permitted.

Monomer and catalyst storage and handling. - The monomers, MMA and TMPTMA, or the premixed monomer system shall be stored in their original shipping containers or in other clean containers as approved by the Contracting Officer. Maximum monomer storage temperature shall not exceed 90 EF. The storage area shall be selected to provide protection from direct sunlight, fire hazard, and oxidizing chemicals. Sufficient ventilation shall be maintained in the storage area to prevent the hazardous buildup of monomer vapor concentrations in the storage air space. The polymerization catalyst shall be stored in accordance with the manufacturer's recommendations, but in no event shall the catalyst storage temperature be allowed to exceed 35 EF. Personnel exposed to monomer or monomer vapor shall use minimum protective equipment as follows: safety eyeglasses, impervious gloves and aprons, and rubber boots as required. As determined by the Contracting Officer, personnel may be required to use full face protective shields, self-contained respiratory equipment, or both. All personnel handling the monomers or catalyst shall be thoroughly trained in their safe use in accordance with manufacturer's recommendations.

Unsafe handling practices will be sufficient cause to discontinue work until the hazardous procedures are corrected. The handling and use of monomer shall in all cases comply with the requirements of applicable Federal, State, and local safety requirements and ordinances.

During the polymerization cycle, the heating enclosure shall be provided with a means of positive ventilation to prevent hazardous concentrations of monomer vapor within the enclosure. Open flame heat sources will not be approved for use during polymerization.

The monomer mixing area shall be free of sources of ignition and shall be well ventilated. Spilled monomer shall be contained with absorptive materials such as vermiculite or dry sawdust and removed with non-sparking equipment.

f. Concrete preparation. - Deteriorated concrete shall be removed from the surface by wet sandblasting or other suitable means. Concrete containing surface contaminants such as oil, paint, or protective coatings shall be cleaned by wet sandblasting or by other approved means to remove these materials. After the removal of these materials, the concrete surface shall be swept and air-blown to remove sand, leaves, trash, gravel, or other miscellaneous loose materials to the satisfaction of the Contracting Officer.

The Contractor shall install a temporary dike along the high side of the area to be impregnated to divert possible rainwater around the area to be impregnated. The Contractor shall also install a temporary dike along the low side of the area to be impregnated to act as a barrier to prevent monomer from accidentally escaping due to an accidental spill or excess application.

g. Application of the surface impregnation process. -

(1) Drying. - After the concrete surface area to be treated has been cleaned in accordance with subparagraph 3.13.f., it shall be uniformly covered with a 1/4- to 1/2-inch thick layer of sand meeting the requirements of subparagraph 3.13.d.(2) and dried to permit polymer penetration. The equipment used to accomplish drying shall consist of a weatherproof enclosure with either an electric infrared, or hot-air heat system, or other technique as approved by the Contracting Officer. Exposed flame infrared heat systems, if selected for drying, shall not be used for polymerization.

Drying shall be accomplished by raising the concrete surface temperature at a rate not exceeding 100 EF per hour to between 250 and 275 EF, and maintaining that surface temperature range for 8 hours. If a higher maximum temperature is desired, approval by the

Contracting Officer shall be obtained. During the drying period, sufficient airflow shall be maintained over the concrete surface to ventilate the water vapor removed from the concrete and to provide uniform concrete surface temperature. During the drying cycle, the Contractor shall obtain continuous or periodic surface temperature measurements, as specified in subparagraph 3.13.b.(3), at a sufficient number of locations over the heated concrete surface [normally one location per 100 square feet] to ensure temperature uniformity. The maximum temperature variation over the heated concrete surface shall not exceed ±20 EF of mean concrete surface temperature at the time measurements are taken.

(2) Cooling. - After the concrete has been dried, it shall be cooled prior to monomer application. The cooling rate for concrete surface temperature shall not exceed 100 EF per hour. Cooling shall continue until the maximum temperature at a depth of 1 inch below the surface of the concrete is 100 EF or less.

During the cooling and impregnation cycles, the dried concrete shall be protected to prevent moisture from reentering the concrete. It may be necessary, if determined by the Contracting Officer, to repeat the drying and cooling cycles prior to monomer application should moisture reenter the concrete.

(3) Monomer mixing. - The monomer MMA and TMPTMA may be premixed in the specified ratio and stored prior to use. Storage of premixed monomer shall be as required in subparagraph 3.13.e. All monomer mixing and transfer equipment shall be as required in subparagraph 3.13.e. All monomer mixing and transfer equipment shall be of explosion proof design and shall be provided with electrical ground cables. Monomer transfer shall be from bottom to bottom of the vessels or through dip pipes in the vessels to prevent the buildup of static charge during transfer. Pipe fittings, valves, pump impellers, or other equipment which will come into contact with monomer shall not be made of copper or brass or certain plastics attacked by the monomer.

(4) Catalyst-monomer mixing. - The polymerization catalyst shall be mixed with the monomer system immediately prior to use. Monomer system temperature at the time of catalyst addition shall not exceed 90 EF. Mixing shall be accomplished with explosion proof equipment in electrically grounded containers in a well-ventilated area.

(5) Impregnation. - Following the drying and cooling cycles, the sand on the concrete surface to be impregnated shall be uniformly leveled if necessary.

The temperature on the surface of the concrete shall not exceed 100 EF at the time of monomer application nor at any time during the impregnation cycle.

Monomer application shall be made at a rate sufficient to uniformly saturate the sand layer to a slight excess without applying so much monomer that it would drain away from the impregnated area. The monomer application rate should be 0.8 pound of monomer per square foot of concrete surface. This is approximately 0.9 gallon per square yard of surface area. However, sand layer thickness, sand particle size, and slope may necessitate application rate adjustment to achieve the described saturation. Following application, the monomer shall be allowed to soak into the concrete for approximately 6 hours. If at any time during the soak cycle the sand should become dry, additional monomer shall be applied as directed by the Contracting Officer.

In order to protect the monomer-saturated sand from the polymerizing effects of direct and indirect solar radiation, monomer application and subsequent soaking shall occur during the time period sunset to sunrise unless the Contractor provides shielding, as approved by the Contracting Officer, to prevent solar radiation from reaching the area being impregnated. Immediately following monomer application, a continuous mylar membrane a minimum of 6 mils thick shall be placed over the monomer-saturated surface to reduce monomer evaporation. This membrane shall remain in place, except for the short periods of monomer application or surface inspection, throughout the impregnation cycle and until the polymerization cycle is complete.

(6) Polymerization. - Polymerization of the monomer impregnated into the concrete shall be accomplished by uniformly heating the treated concrete to a surface temperature of at least 165 EF and not exceeding 185 EF and maintaining it for a minimum of 5 hours. The rate of temperature increase and allowable surface temperature variation shall be as required in subparagraph 3.13.g.(1).

The equipment and procedures used to accomplish heating of the concrete for polymerization shall be of the type described in subparagraph 3.13.g.(1) as approved by the Contracting Officer. See subparagraph 3.13.b.

(7) Cleanup. - Following completion of the surface impregnation treatment process, the Contractor shall remove the sand from the concrete surface and dispose of the sand at the site as directed by the Contracting Officer.

3.14 SILICA FUME CONCRETE

a. General. - Silica fume concrete shall be used to repair concrete damaged by abrasion-erosion action. Silica fume concrete may also be used in the infrequent occasions where a high strength (compressive strength in excess of 10,000 lbs per square inch) repair concrete is required. Silica fume concrete shall be used on areas of damaged concrete greater than 1 square foot having a depth greater than 6 inches or a depth extending 1 inch below or behind the backside of reinforcement. If the depth of repair is at least 2 inches but less than 6 inches, epoxy bonding agent shall be used in accordance with the provisions of paragraph 3.8, to bond fresh silica fume concrete to concrete being repaired. Silica fume concrete shall not be used for repairs that are less than 2 inches in depth.

b. Submittals. - The Contractor shall submit certification of compliance for materials in accordance with subparagraph d. below.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - All concrete materials shall be obtained from previously tested and approved sources. Materials will be accepted on certificate of compliance with the following ASTM Standards:

(1) Portland cement. - Portland cement shall meet the requirements of ASTM C 150 for type I, II, or V cement. The specific cement type

shall be as directed by the Contracting Officer and determined by the environment in which the repair is conducted.

(2) Silica fume. - The silica fume mineral admixture shall be obtained as a byproduct from the manufacture of solely silicon metal in electric blast furnaces. The condensed silica fume shall be processed and sized to a fineness of approximately 200,000 cm^2 per gm (20,000 m^2/kg) at a porosity (t) of 0.500 when tested in accordance with ASTM C 204 and have an amorphous silica ($Si0_2$) content of not less than 85 percent of the total fume. When tested in accordance with ASTM C 311, the silica fume shall have a moisture content of less than 3 percent and a loss on ignition of not greater than 6 percent. A manufacturer's certificate of compliance with these requirements and applicable provisions of ASTM C 618 is required. The silica fume shall be supplied, proportioned and combined with other admixtures, as necessary, from a supplier regularly engaged in the sale of this combination product as a concrete admixture. This combination admixture shall be batched with the concrete in either of two forms or types.

(a) The wet type shall consist of water slurry containing approximately 45 percent silica fume solids with a water-reducing admixture meeting all requirements specified.

(b) The dry form shall be a densified powder blended with a dry water reducing admixture. Both types shall be compatible with a water reducing admixture that could be added at the concrete plant or at the placement site.

(3) Admixtures. - The Contractor shall furnish air-entraining and chemical admixtures for use in concrete.

(a) Air-entraining admixture shall be used in all silica fume concrete and shall conform to ASTM C 260.

(b) Chemical admixtures. - The Contractor may use type A, D, F, or G chemical admixtures. If used, they shall conform to ASTM C 494.

(c) Use of other admixtures must be approved by the Contracting Officer.

(4) Water. - The water used in making and curing silica fume concrete shall be free from objectionable quantities of silt, organic matter, salts, and other impurities.

(5) Aggregate. - The term "sand" is used to designate aggregate in which the maximum size particle will pass a 4.75-mm (No. 4) sieve. The term "coarse aggregate" is used to designate all aggregate which can be retained on a 4.75-mm (No. 4) sieve. Sand and coarse aggregate meeting the requirements of ASTM C 33 shall be used in all concrete.

(6) Curing compound. - Wax-base (type I) and water-emulsified resin-base (type II) curing compounds shall conform to the requirements of Reclamation's "Specifications for Concrete Curing Compound" (M-30) dated October 1, 1980.

(7) Evaporation retarder. - Monomolecular membrane evaporation retardant formulated for use with silica fume concrete requirements shall be equal to "Confilm", manufactured by Master Builders, Lee at Mayfield, Cleveland, OH 44118.

e. Safety. - All work shall be performed in accordance with paragraph 1.6.

f. Concrete preparation. - After damaged or unacceptable concrete has been removed as specified in section 2. the surface on which the silica fume concrete will be placed shall be prepared. An acceptable surface shall have the appearance of freshly broken, properly cured concrete. The surface shall be free of any deleterious materials such as free moisture, ice, petroleum products, mud, dust, carbonation, and rust. The perimeters of the repair shall be saw cut to a minimum depth of 1 inch.

The clean surface is not ready to receive repair silica fume concrete until it has been brought to a saturated, surface-dry condition. This condition is attained by saturating the surface to a depth that no concrete mixture water may be absorbed from the fresh concrete. Then, just prior to placing concrete against the surface, all free moisture (moisture capable of reflecting light) shall be removed from the prepared surface.

g. Application. - Silica fume concrete shall be composed of cement, silica fume, coarse aggregate, sand, water, and approved admixtures, all well mixed and brought to the proper consistency. Silica fume concrete mixtures shall be proportioned in accordance with Reclamation's "Concrete Manual", Eighth Edition, revised, chapter III, except that silica fume shall be added to the mixture at a ratio of 7 to 12 percent by mass of the portland cement as directed by the Contracting Officer. The water-cementitious ratio of the concrete (exclusive of water absorbed by the aggregates) shall not exceed 0.35 by weight. Slump of the silica fume concrete, when placed, shall not exceed 3 inches for concrete in slabs that are horizontal or nearly horizontal and 4 inches for all other concrete. Silica fume concrete with less slump should be used when it is practicable to do so. The concrete ingredients shall be thoroughly mixed in a batch mixer. The concrete, as discharged from the mixer, shall be uniform in composition and consistency from batch to batch.

(1) Forms. - Forms shall be used for silica fume concrete whenever necessary to confine the concrete and shape it to the required lines. The forms shall be clean and free from encrustations of mortar, grout, or other foreign material. Before silica fume concrete is placed, the surfaces of the forms shall be coated with a form oil that will effectively prevent sticking and will not soften or stain the concrete surfaces or cause the surfaces to become chalky or dust producing.

(2) Placing. - Placing of silica fume concrete shall be performed only in the presence of an authorized representative of the Contracting Officer. Placement shall not begin until all preparations are complete and the authorized representative of the Contracting Officer has approved the preparations. Silica fume concrete shall not be placed in standing or running water unless, as determined by the Contracting Officer, the structure under repair cannot be economically dewatered. If underwater silica fume concrete placement is required, special placing procedures shall be required. A suggested guide is ACI 394R.

When appropriate, silica fume concrete shall be placed in layers not greater than 20 inches thick. Each layer, regardless of the thickness, shall be adequately consolidated using immersion-type vibrators or form vibrators when approved. Adequate consolidation of silica fume concrete is obtained when all undesirable air voids, including the air voids trapped against forms and construction joints, have been removed from the concrete.

(3) Finishing. - The class of finish required shall be a finish closely resembling the finish of the surrounding concrete. Silica fume concrete does not normally develop bleed water and special finishing procedures may thus be required. The ambient temperature of surfaces being finished shall be not less than 50E F. Immediately following placement of silica fume concrete to finished grade, the surface shall be screeded to bring the surface to finished level with no coarse aggregate visible. No cement or mortar shall be added to the finishing operation.

A monomolecular membrane evaporation retarder shall be applied to the surfaces of the silica fume concrete, in accordance with manufacturer's recommendations, immediately after the screening operation.

Floating, if necessary to achieve the specified finish, shall be performed immediately following the application of evaporation retarder.

h. Curing and protection. - Proper curing of silica fume concrete is essential if bond failure and shrinkage cracking are to be eliminated. Silica fume concrete repairs shall be cured, preferably by water curing, or alternately, by application of a uniform and continuous membrane of wax-base (type I) or water-emulsified resin-base (type II) curing compound meeting the requirements of subparagraph 3.6.d.(6). and as approved by the Contracting Officer. If the use of curing compound is approved, daily inspection by the Contractor shall be performed to ensure the maintenance of a continuous, water-retaining film over the repaired area. The water-retaining film shall be maintained for 28 days after the concrete has been placed.

Silica fume concrete surfaces to which curing compound has been applied shall be adequately protected during the entire curing period from pedestrian and vehicular traffic and from any other possible damage to the continuity of the curing compound membrane. Areas where curing compound is damaged by subsequent construction operation within the curing period shall be resprayed.

Water curing shall commence immediately after the concrete has attained sufficient set to prevent detrimental effects to the concrete surface. The concrete surface shall be kept continuously wet for a minimum of 14 days. Whenever possible, silica fume concrete shall be water cured by complete and continuous inundation for a minimum period of 14 days.

The Contractor shall protect all silica fume concrete against damage until acceptance by the Government. Whenever freezing temperatures are imminent, the Contractor shall maintain the newly placed repair concrete at a temperature of not less than 50 EF for 72 hours. Water-cured silica fume concrete shall be protected from freezing for the duration of the curing cycle and an additional 72 hours after the water is removed.

3.15 ALKYL-ALKOXY SILOXANE SEALING COMPOUND

a. General. - A concrete sealing compound is defined as a liquid that is applied to the surface of hardened concrete to prevent or decrease the penetration of liquid or gaseous media, such as water, aggressive solutions, and carbon dioxide, during the service exposure, preferably after initial drying to facilitate its absorption into voids and cracks. An alkyl-alkoxy siloxane sealing compound, herein after referred to as siloxane, shall be applied to concrete surfaces when it is desired that application of a sealing compound cause no change in the appearance of the sealed surfaces.

The sealing of concrete surfaces with siloxane shall be in accordance with these specifications.

Siloxane sealing compound shall not be used to seal concrete subject to frequent or permanent immersion in water; nor shall it be used on concrete surfaces exposed to high abrasion forces.

b. Submittals. - The Contractor shall, before starting work, shall submit to the Contracting Officer manufactures data and certification that the concrete cleaner and siloxane sealing compound furnished by the Contractor meets the requirements of this specifications. The chemical constituents shall correspond to the requirement of subparagraph 3.15.d.

A MSDS shall be furnished to the Contracting Officer prior to shipment of material with information pertaining to the safe practices for storage, handling and disposal of the materials and their explosive and flammable characteristics, health hazards, and the manufacturer's recommended fire fighting techniques. The MSDS shall be posted at all storage areas and at the job site.

The Contractor shall furnish, for approval, a detailed written description of the methods the Contractor plans to use to apply the siloxane and for clean up of all spills and residue in open containers.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - The siloxane sealing compound shall be a clear, ready to use sealer based on oligomeric alkyl-alkoxy siloxane containing not less than 20 percent active siloxane solids by mass.) The compound when properly applied to concrete shall conform to the following performance standard:

Chloride screening	91% (minimum)	(NCHRP 224, Series I)
Reduction of Chlorine Penetration vs untreated concrete	92.4(minimum)	(NCHRP 224, Series IV)
Moisture Vapor Transmission	97.5%(minimum)	(ASTM E-96)
Water Repellency Rating	92%(minimum)	(ASTM C-140, ASTM C-67)
Water Absorption	1.40%(maximum)	(ASTM C-67, ASTM C-140)
Scaling Resistance to Deicers	Excellent	(ASTM C-672)
Resistance to Chlorine Penetration	0.07 lbs/cu.yd. (maximum)	(AASHTO T-259/260)
Surface Friction Reduction	0	(ASTM E-303)
Penetration (1 application)	1/8" - 1/4"	

The compound shall have a high flash solvent carrier with a strong chloride screen and shall exhibit alkaline stability and form a chemical bond with the treated concrete.

The concrete sealing compound shall be Consolideck SX as manufactured by ProSoCo Inc., P.O. Box 1578, Kansas City, KS 66117, (913) 281-2700, or approved equal.

e. Safety. - The Contractor shall take the necessary precautions to avoid wind drift onto auto and pedestrian traffic. The materials shall be stored, handled, and applied in accordance with the manufacturer's or supplier's recommendations. Storage of all materials may be in the original shipping containers. The material should be stored in sealed containers and kept away from extreme heat. The sealant contains blended solvents and should be handled accordingly. Do not use near fire or extreme heat and provide good ventilation to avoid buildup of solvent fumes. Personnel applying the concrete sealant shall wear NIOSH/MSHA approved respirators, goggles, rubber gloves, and plastic or rubber suits to avoid splash to skin and eyes. Clothing that becomes contaminated with the concrete sealant shall be changed as quickly as possible.

Unsafe handling practices will be sufficient cause to discontinue work until the hazardous procedures are corrected. The handling and use of the concrete sealant shall in all cases comply with the requirements of applicable federal, state, and local safety requirements and ordinances.

f. Concrete preparation. - The concrete surfaces to be treated shall be clean and physically sound. Unsound or deteriorated surfaces shall be removed in accordance with the requirements of section 2. All needed repair work shall be adequately cured prior to application of the siloxane.

Concrete surfaces shall be prepared by power sweeping and blowing with high pressure air to remove all dirt and foreign material from the surface and from all cracks. Contaminants, such as asphalt and heavy oil and rubber stains, shall be removed at the discretion of the Contracting Officer by scraping and cleaning with solvents. Well bonded surface contaminants and existing painted surfaces shall be removed by high pressure water blasting or wet sand blasting. The concrete surface and all cracks shall be completely dried prior to the application of the siloxane.

g. Application. - If the concrete sealant is a product other than Consolodeck SX, a test application of the concrete sealant shall be made to an area selected by the Contracting Officer using the same equipment and procedures proposed for the project. The test procedure is to insure compatibility of the product, to determine the waterproofing results and to check for surface discoloration from the procedure. The Contractor shall not proceed with the remainder of the work until the Contracting Officer approves the results of the test application. If the results of the test application are deemed unsatisfactory by the Contracting Officer, the Contractor shall modify his sealant materials, procedure, and/or equipment as directed by the Contracting Officer and the test application shall be repeated.

The siloxane sealant shall not be applied at surface and air temperatures below 40 degrees F, or above 100 degrees F. Surfaces shall be treated within 24 hours after the surface preparation is completed. The prepared surfaces shall be maintained in a dry condition and protected to prevent contamination prior to the siloxane application. If the prepared surface becomes contaminated, it shall be recleaned in accordance with paragraph 3.15.f. The Contracting Officer shall determine if the surface is dry enough to receive sealant. If the Contracting Officer determines that the surface is too damp for application of the sealant, application of the sealant shall not commence without approval of the Contracting Officer.

The sealant shall be applied with low pressure (20) psi airless spray equipment fitted with solvent resistant hoses and gaskets. Heavily saturated brush or roller may be used in isolated incidents if the Contracting Officer determines that brush or roller application is the most effective means.

Adjoining glass, metal and painted surfaces shall be protected from overspray and splash of the siloxane sealant. Any accidental or unintentional overspray or splash on adjoining glass, metal or painted surfaces shall be removed using mineral spirits before the solution has dried on the surface.

When applying to exteriors of occupied areas, all exterior air conditioning and ventilation vents shall be covered during application and air handling equipment shall be turned off during application to avoid solvent odors within the occupied areas.

The concrete surfaces shall be given a full and complete application of the siloxane sealant at the following application rate of 80-120 sq.ft./gal.

(1) Horizontal surfaces. - When applying the siloxane to flat horizontal concrete surfaces, the siloxane shall be applied in two "wet-on-wet" coats. Flood the surface and broom or squeegee the material around for even distribution. Allow the surface to absorb the siloxane and follow immediately with a second application before the surface dries. Puddles of excess siloxane sealant shall be broomed out thoroughly until they completely penetrate into the surface.

(2) Vertical surfaces. - When applying the siloxane to vertical surfaces, the siloxane shall be applied in two "wet-on-wet" applications. Apply the siloxane in a flooding application, from the bottom up with sufficient material applied to produce a 6" to 8" rundown below the contact point of the spray pattern with the concrete surface. Allow the first application to penetrate the surface (approximately three to five minutes) and reapply in the same saturating manner. If the siloxane sealant is applied to surfaces of extremely dense, mirror finish concrete the Contracting Officer may direct that the siloxane be applied in one saturating application to prevent surface darkening.

h. Curing. - The treated areas shall be protected from rain and foot traffic for six hours after application. Vehicular traffic will not be allowed on the treated area until after 24 hours after the application of the siloxane.

i. Measurement for Payment. -

(1) Measurement for payment of surface preparation of the concrete surfaces will be made of the actual surface area prepared. Payment for surface preparation will be made at the unit price per square foot bid therefor in the schedule, which unit price shall include all costs of preparing the concrete surfaces for the siloxane as specified in paragraph 3.15.f.

(2) Payment for seal coating of the concrete surfaces will utilize the same area as measured for the surface preparation. Payment for seal coating of concrete surfaces will be made at the unit price per square foot bid therefor in the schedule, which unit price shall include all costs for storing and handling materials, of applying the siloxane system, of cleanup, and of providing all the necessary safety equipment, and any other work required under these specifications to properly complete the job.

Notes