TECHNICAL MEMO

Prepared By: Water Resources Management Division (WRMD)
Date: March 2022
Re: Animal Burrows on Earthen Dams

Background

This memo is part of a series of documents on dam emergency interventions. The focus of this memo is to provide guidance on Animal Burrows on Earthen Dams. The impact of wildlife interaction with earthen dam structures can be difficult to determine. Animals generally cause external erosion through grazing and trafficking, while burrowing animals create cavities of different size, location, and levels of interconnection though structures (Mousa & Meguid, 2011, pg. 3). The extent and influence of internal intrusions may not be fully appreciated as there is a general lack of understanding and research regarding "burrowing mechanics and subsequent failures in earthen structures" (Mousa & Meguid, 2011, pg. 21). While there have been failures of earthen structures attributed to wildlife intrusions, at least partially, most literature refers to burrowing animals as an ongoing maintenance issue.

The Federal Emergency Management Agency (FEMA) released the *Technical Manual for Dam Owners: Impacts of Animals on Earthen Dams* (2005) which outlines the threat and management options for 23 North American species. The Manual established guidelines to determine when wildlife management should occur and the methods that should be undertaken during rehabilitation. In the United States, most states have updated their individual guidelines to be in accordance with, or simply refer to, the FEMA Manual. There does not appear to be an overarching standard approach to burrowing animal mitigation in Canada, or internationally.

Potential Negative Impacts Caused by Burrowing Animals

The FEMA Manual outlines two main dam safety problems caused by animal activity:

1. **Hydraulic alteration through distortion of the established phreatic surface** - Burrows have the potential to "shorten seepage paths, increase seepage volumes, decrease the factor of safety against slope failure, and cause internal erosion of embankment materials (piping)" (FEMA, pg. 5). Burrows established on the upstream slope can result in the normal pool elevation being allowed to extend inward, shortening the phreatic surface (Figure 1), while downstream burrows "can allow the phreatic surface to day-light higher on the downstream slope" (FEMA, pg. 5).

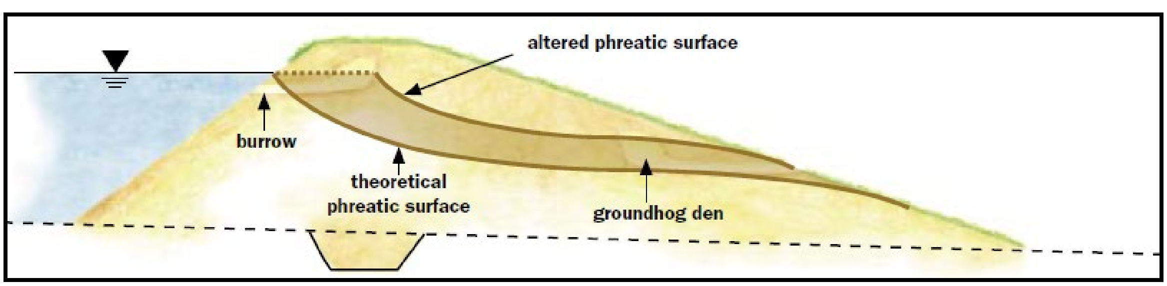

Figure 1 – Cross section of an earthen dam with an altered phreatic surface: burrows up and downstream can alter dam hydraulics by shortening seepage paths. Intrusions from both sides can create dangerously close tunnel networks, while downstream burrows are likely to expedite the risk of backward erosion piping. Retrieved from FEMA, pg. 6.

2. **Structural integrity losses due to the voids created by burrows** - Soil surrounding burrows may be loosened and more susceptible to collapse due to: insufficient compaction during construction; heavy precipitation and seasonal run off, or; application of excessive load, particularly vehicular traffic (FEMA, pg. 5). The severity of the collapse is dependent on

the depth and size of a den or tunnel network since the deformation will increase as it propagates upward (Figure 2) (FEMA, pg. 6).

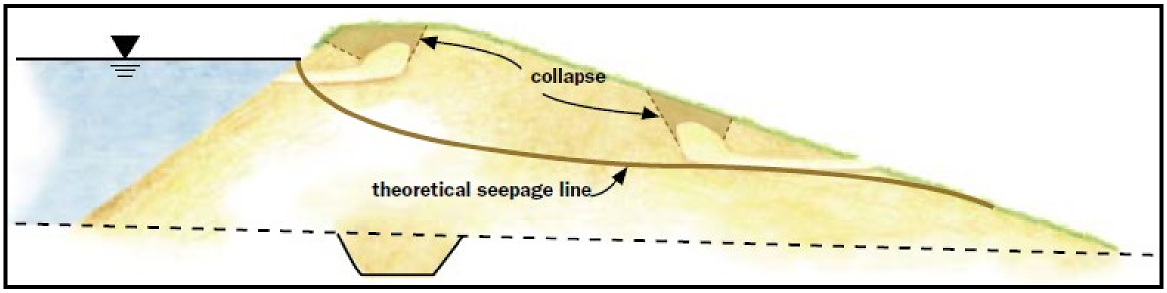

Figure 2 - Cross section of an earthen dam with borrows which can collapse, leading to formation of sinkholes and loss of structural integrity. Retrieved from FEMA, pg. 7.

Piping is likely to begin in a downstream burrow, with the water flowing through the dam depositing internal soil particles; “water pressure and flow generally increase further into the earth dam, along with the rate of movement of soil particles” (Mousa & Meguid, 2011, pg. 6). Additionally, the presence of both waterside and landside burrows has the potential to create dangerously close tunnel networks which can significantly narrow a section. The potential risks associated with animal burrows are dependent on the size of an earthen structure and accompanying reservoir.

It can be difficult to distinguish the independent effects of an altered phreatic surface and structural integrity losses as the evidence of the animal burrows can easily be washed away into adjacent waterways (Mousa & Meguid, 2011, pg. 2). Internal erosion may initially occur inside an animal burrow, or infiltration of rain and high water levels may reduce shear strength of the soil, leading to macro-instability (Taccari, pg. 2). Figure 3 (left) shows the breach of a levee in Italy after heavy rainfall inundated a significant burrow network. The event was determined to be caused by animal burrows due to previous site inspections and analysis of the burrow network in the location of the breach (Figure 3, middle), and a coinciding smaller breach which originated within downstream burrows (Figure 3, right). An additional summary of select failures related to animal activities has been presented in Figure 4.

Figure 3 – Left: Significant breach on the Panaro riverbank (Italy) in 2014. The area was known to have significant animal burrows. Middle: Badger footprints and a burrow entrance were observed in 2010 and 2012 at the same area as the breach (left). Right: On the same day as the breach (left), internal erosion caused a smaller breach in an area downstream, which also had animal burrows. Images retrieved from Taccari, 2015, pg. 25 & 134.

Case	Location	Date (M/Y)	Failure mode
Sid White Dam	Near Omak, WA	05/1971	Seepage through animal burrows. Caused second dam to fail and dumped debris into town of Riverside
Lower Jones Tract	California Delta	09/1980	Seepage and rodent activities
Water's Edge Dam[a]	North of Cincinnati, Ohio	10/1992	Water flow through animal burrows
Iowa Beef Processor Waste Pond Dam[a]	Wallula near Richland, Washington	01/1993	Uncontrolled seepage through the animal burrows, exiting on the downstream face and causing erosion
Persimon Creek Watershed—Site 50	Mississippi	06/1998	The dam failed due to erosion of an emergency spillway. Ongoing beaver activities clogged primary spillway
Sunrise Duck Club (Suisun Marsh)	Suisum Marsh, California	07/1999	High tide and possible beaver activities
Pischieri Pond Dam[a]	Cleveland, Ohio	1999	The dam was breached when an inspection found a void in the dam.
Upper Jones Tract	California Delta	06/2004	High tide, under-seepage and rodent activities
Foenna Stream[a]	Sinalunga, Italy	01/2006	Porcupine burrow, internal erosion and levee subsidence
Truckee Canal	Fernley, Nevada	01/2008	Woody vegetation and animal burrows present
Pin Oak levee[a]	Winfield, Missouri	06/2008	Muskrat burrows

[a] These cases are described in "Reported and potential failures"

Figure 4 - Selected levee breaches and dam failures (or near failure) related to animal activities. Image taken of Table 5, retrieved from Mousa & Meguid, 2011, pg. 16.

<u>Burrowing Animals in Newfoundland and Labrador</u>

Fisheries and Land Resources identified 27 native and introduced land mammal species on the island of Newfoundland, and 38 on Continental Labrador. A summary of the mammals which could have an impact on earthen dams has been presented in Table 1. There were no notable birds, reptiles, amphibians, fish, mollusks, or invertebrates which would cause significant impact on an earthen structure.

The severity of damage experienced at any site is dependent upon the species type, population, and typical activities, as well as the "geometry, material, and condition of the earthen structure" (Mousa & Meguid, 2011, pg. 4). The muskrat, river otter, and beaver, all active on the waterside, are considered to have the most significant impact on internal erosion and structural integrity losses. The typical burrow and activities of these species are far deeper, wider spreading, and more likely to have entrances obscured by water. Rodents, and the remaining burrowing species, generally only form shallow borrows which do not penetrate more than 30 cm below the surface. The ermine and fox do not burrow but are included on the list because they typically excavate existing burrows to capture prey.

Inspection

There are a variety of general and species-specific indicators which could be identified through biological considerations during an engineering inspection (FEMA, pg. 8). It is common for dam inspection sheets to include a section for remarks concerning animal activity, usually grouped with vegetation and other visible characteristics. To accurately assess the presence of wildlife, inspectors must be familiar with local wildlife, be able to identify typical intrusion locations of specific animals and have a methodology for evaluating observed deficiencies. The FEMA Manual (pg. 12) suggests that an inspector be able to observe issues which can indicate animal activity, including: "animal burrow entrances, mounds of excavated soil, cracks, depressions, erosion, sinkholes, paths and ruts, sloughs, slides, and scarps". Further, the inspector should assess the severity of the deficiencies, and if they would warrant further "monitoring, repair, or investigation" (FEMA, pg. 8). The FEMA Manual (pg. 8-14) outlines specific zones along with the wildlife, intrusions, and deficiencies which may result:

- Zone 1 - Upstream slope: Aquatic burrowers (muskrat and beaver), generally have an entrance from 15 cm to 1.2 m below the waterline, burrowing upward toward the crest. Otter entrances may be indicated by slides on slopes and bare areas where they repeatedly enter the water.
- Zone 2 - Dam Crest: Dens (muskrat and beaver) are usually just below the crest. There may be depressions which indicate partial collapse of the burrow. Vehicular traffic and well-compacted material may discourage terrestrial wildlife from burrowing.
- Zone 3 - Upper downstream slope: Attractive for terrestrial animal activity, both for burrowers and predators. There may be large dens, burrows, and piles of dirt outside of small burrows. Animals, notably beavers, may be attracted to this area if there is thick vegetation.
- Zone 4 - Lower downstream slope: Supports terrestrial animals, but less attractive due to possible saturation and flooding of burrows.
- Zone 5 - Downstream toe area: Less likely to support burrowing animals due to risk of flooding.
- Zone 6 - Spillway, outlets, and general areas: Look for beaver dams and gnaw marks on tree trunks, particularly if vegetation and forest fringe are adjacent.

Table 1 – Summary of burrowing animals which exist in Newfoundland and Labrador and have the potential to negatively impact earthen structures. The woodchuck and two varieties of lemming are only found Labrador, with all other mammals inhabiting the island and continental portions of the Province.

Summary of Burrowing Animals in Newfoundland and Labrador			
Species	**Typical Burrow**	**Active Side**	**Reference**
Muskrat	Large burrows with entrance below water surface (3m), with upward digging into the embankment to create significant internal burrows	Waterside	Newell, T. L., (n.d.).
River otter	Large bank dens with above and below water entrance	Waterside	Dewey, T., & Ellis, E. J., (n.d.).
Beaver	Large tunnels with entrance below water surface (1m), or above and covered with mud, sticks, and rocks.	Waterside	Anderson, R. & Dewey, T. (n.d.).
Woodchucks	Burrow system with multiple entrances and large cavities (45cm), tend to avoid damp areas, winter burrows below frost level	Landside	Kelsall, J. P. & van Zyll de Jong, C. G., (1991).
Ermine (Weasel)	Do not burrow; widen existing burrows to live in and catch mice/prey	Landside	Poor, A. & Loso, H., (n.d.).
Lemming, shrew, and mice	Shallow burrow system with side chambers (max depth 30 cm)	Landside	(n. a.), (n.d.). Rodents
Red fox	Do not burrow; widen existing burrows as they dig out prey	Landside	Fox, D. L. & Dewey, T., (n.d.).
Rat, moles, voles, mice, and shrews	Extensive burrows system, can have surface mounding	Both	(n. a.), (n.d.). Rodents
Eastern Chipmunk	Extensive burrows directly underneath or next to cover (6-15cm in diameter, and between 1 and 10 m long)	Both	Sheppard, D. & Aniskowicz, B. T., (1989).

The presence of vegetation on earthen dams limits the effectiveness of visual inspections. Routine maintenance, which includes animal control and vegetation management, may not be deemed necessary, or may be too expensive, for dam owners to complete regularly. Burrow entrances, and other intrusion indicators may not be visible if the area is covered with thick grass or woody vegetation. Some animals may be attracted to structures covered in vegetation because they offer additional protection from predators, or a food source (FEMA, pg. 58). The roots from trees and woody vegetation loosen soil and may also facilitate burrowing (Figure 5). Since animal burrows are typically referred to as a nuisance problem, and not typically credited as being the main cause of structural failure, associated risks may be underestimated and restoration postponed.

Management Techniques

Once the intrusions of burrowing animals have been discovered, the extent of a burrow can be identified using "gravity survey, resistivity methods, seismic reflection, and Ground Penetrating Radar (GPR)" (Mousa & Meguid, 2011, pg. 14). This can assist with identifying the specific species and determining the animal control method which should be applied, and the extent of required restoration. It may be preferable to consult with knowledgeable specialists in an area, specifically wildlife experts or local trappers, to confirm the identification prior to pursuing a management technique. Maintenance operations must account for endangered habitat and species, as well as water quality, and other environmental regulations.

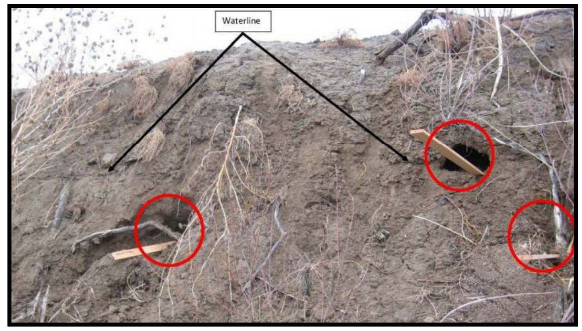

Figure 5 – Muskrat burrows accompanied by tree roots on an earthen slope. Three burrows, initially marked by pieces of wood, are indicated with red circles. A waterline appears to intersect the upmost burrow entrance, and fall above the other two burrows. Retrieved from Hahn et al (n.d.), slide 85.

1. **Non-Lethal Control** - Non-lethal control is focused on removal of the animals causing a problem or deterring future intrusions in an area. The four main approaches include (Fail & Preven, pg. 12-13):
    1. Live-trapping: remove problem wildlife, with relocation to suitable areas.
    2. Repellent: discourage activity by applying repellent, such as an acrylic paint and sand abrasive on tree trunks to deter beavers.
    3. Exclusion: place screens, metal, plastic, riprap, or other barriers to physically impede wildlife.
    4. Habitat modification: use herbicides to remove food base.

These methods are generally less intrusive on ecosystems, and do not specifically impact non-target wildlife. In some cases, it may be too expensive or impractical to implement ongoing non-lethal control. Additionally, there is no guarantee that the measures undertaken will be effective, Figure 6 shows the reoccurrence of a beaver dam in an area which had previously had non-lethal removal and structural repair.

Figure 6 – Left: Entrance to a beaver burrow coincides with tree root (bottom of image), other exposed roots also visible. Right: Reoccurrence of intrusion after a previous repair was completed. Image retrieved from Roa et al, 2014, pg. 41.

2. **Lethal Control** - Lethal control may be preferable when non-lethal options are deemed ineffective, or prohibited by site-specific parameters, such as location, ecosystem, or cost. Three main approaches include (Fail & Preven, pg. 13-14):
    1. Poison bait or toxicant: application is non-selective and may result in significant mortality of non-target wildlife, survivors may avoid treated bait, and there may be public discontent or backlash.
    2. Trapping and snares: application is non-selective, labour intensive, and bait may decompose.
    3. Shooting: time consuming and ineffective.

3. **Restoration** - Restoration is applicable when minor intrusions have occurred and the area is free of cracking and slumping, or other signs of embankment stress. Shallow burrows located near the surface may be tamped or rodded with backfill soil or impervious material (Mousa & Meguid, 2011, pg. 15). It is important to confirm the species and their typical burrow system to determine if backfill will be an effective restoration method. Success of the backfilling technique is dependent on matching compaction to that of the surrounding structure and ensuring that cavities or weak spots are eliminated.

   Larger burrows, or those out of reach of compaction tools, may be filled by "mud-packing". The process involves pouring a slurry of 90% earth, 10% concrete, and water, through a vertical pipe into a cavity. Once filled, the pipe is removed and dirt is placed to cap the entrance so that native grass can be permitted to grow (FEMA, pg. 58). Success of the mud-packing technique is dependent on the slurry infiltrating the entire burrow network. For networks with many intersecting tunnels and internal cavities, there is an increased chance that the slurry will not be able to penetrate the full network. Apply pressure during mud-packing is not recommended as the mixture may induce fracking, with either air or the slurry mixture, and further exasperate the issue.

4. **Repair** - If embankment stress is visible, excavation with shovels or backhoe is the suggested remedy. Importance is placed on minimizing potential consequences of "soil removal, including slope instability and increased hydraulic gradient" (FEMA, pg. 59). Where a burrow extends through a dam section, the upstream entrance must be "excavated and backfilled with impervious material, plugging the passage entrance so that reservoir water is prevented from saturating the dam's interior" (Mousa & Meguid, 2011, pg. 15). Following success of the upstream repair, the excavation and backfill would be repeated on the downstream slope. Again, pressurized application of fill material is not recommended due to the increased pressure and likelihood of fracturing the internal structure.

   The FEMA Manual recommends placing immediate priority on repairs to "animal penetrations that exhibit seepage, soil migration, or have caused slope instability in Zones 1, 4, or 5" (FEMA, pg. 64); followed by analysis of major repair requirements, and completion of construction in subsequent years. Due to the winding nature of animal burrows, and the likelihood of intrusion reoccurrence, it is difficult to ensure that all hidden burrows are removed or filled. Where existing burrows remain, the structural integrity can be weakened and remain at an increased risk of failure.

5. **Mitigation** - Design of new embankment structures can include preventative measures targeted at mitigating intrusions from specific species. Typically, waterside activity can be deterred by inclusion of riprap accompanied by a liner which runs 1.2 m below the water surface. Additionally, constructing the upstream slope with a slope of 3H to 1V, and a downstream slope of 2H to 1V may deter muskrat and beaver, which prefer steeper slopes (FEMA, pg. 64). Beavers and otters may be deterred by protective fencing. Rectangular (Figure 7) and trapezoidal (Figure 8) fencing surrounding culvert entrances, with openings of less than 10cm, are particularly effective against beaver dam formation. Otters are more likely to disrupt and distort fencing to gain entrance so regular inspection would be required (FEMA, pg. 70). Landside mitigation techniques for dams are also outlined in the FEMA manual.

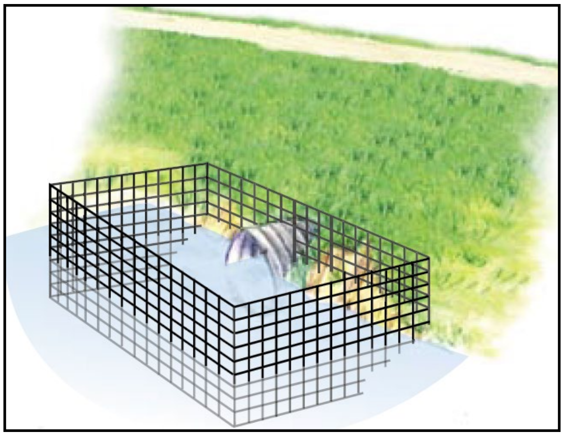

Figure 7 – Rectangular fencing around culvert to deter beaver damming. Culvert and surrounding area of dam are encased by fencing. Image retrieved from FEMA, pg. 66.

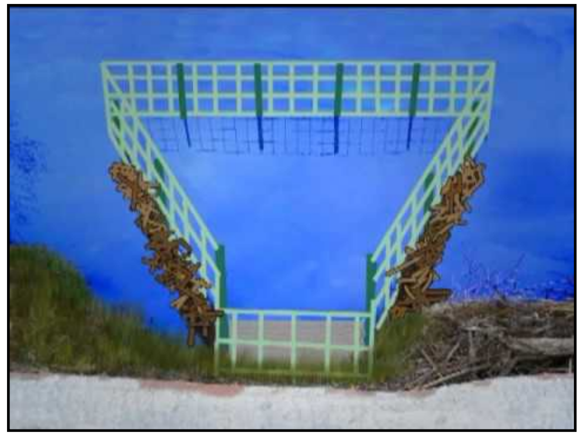

Figure 8 - Trapezoidal fencing around culvert to deter beaver damming. Culvert entrance at bottom of figure with debris caught by fencing. Image retrieved from Perryman, 2010.

Conclusions

The decision to remove animals and restore, or repair earthen dams is a dam safety and performance issue. The FEMA Manual (2005) forms the basis for many existing animal control policies, but no singular set of criteria and remediation methods have been universally accepted. The impact which burrowing animals have on structural integrity is disputed due to the fact that many intrusions are not noticed, documented, or investigated in a timely manner. Where failures do occur, evidence of a burrow is destroyed, removing the chance to study the cause and propagation of the failure.

In some cases, it is prohibitively expensive to perform ongoing animal control, and restoration techniques may be undertaken as a routine maintenance issue. Where burrows are discovered, it is recommended that they be restored, if possible, by filling with tamped soil or mud-packing. Where more intensive repair is required, excavation of the burrow system must be undertaken. Due to the nature of various burrowing animals, backfilling techniques may be ineffective at removing all internal cavities and structural issues may remain.

There are three burrowing animals in Newfoundland and Labrador which have been attributed to causing failures in earthen structures in other jurisdictions; the muskrat, river otter, and beaver. These mammals are considered to have deep, wide spreading burrows with the greatest potential to instigate internal erosion and lead to a loss of structural integrity. These animals are all active on the waterside and more likely to have entrances obscured by water. Rodents and other burrowing animals are all active on the downstream slope and may be attracted to overgrown vegetation. External burrow entrances are far more likely to be overlooked during visual inspection of overgrown earthen structures.

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