TECHNICAL MEMO

Prepared By: Water Resources Management Division (WRMD)
Date: October 2023
Re: Vegetation 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 vegetation on Earthen Dams. Vegetation on earthen dams was not always considered to be a cause of serious structural deterioration. Some older designs included planting of trees and woody vegetation, while historic maintenance did not place importance on removal of new growth. The US Federal Emergency Management Agency (FEMA) released the *Technical Manual for Dam Owners: Impacts of Plants on Earthen Dams* (2005) which became a design benchmark within the US and internationally. The Manual established buffer areas where vegetation should be monitored, maintained, or removed. Most States have updated their individual guidelines to be in accordance with the FEMA Manual. Further specifications were outlined by the US Army Corps of Engineers' (USACE) in the *Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures* (2014).

An overarching Canadian standard approach to vegetation on, and around earthen dams, does not currently exist (Canadian Dam Association, pg. 4). Guidelines have been established by hydroelectric companies operating in specific Provinces (Demers, et al., Dawe, P., personal communication, Sep 4, 2019), but they are not consistent, easily accessible, or clearly delineated.

Potential Negative Impacts Caused by Vegetation Growth

The FEMA Manual (FEMA, 2005, Pg. 2-5) outlines the following dam safety problems caused by woody vegetation growth:

- Uprooted trees can produce large voids and reduced freeboard; and/or reduce the cross-section for maintaining stability.
- Decaying roots can create seepage paths and internal erosion problems.
- Interference 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.
- Root penetration of conduit joints and joints in concrete structures.

Internal erosion caused by root systems of established vegetation may not be outwardly evident. Vegetation on the downstream slope alters the line of saturation and seepage line

(Figure 1). When vegetation dies, soil moisture uptake is reduced, causing the seepage line to move upward and reduce the zone of aeration (FEMA, 2005, Pg. 4-11). This increase may submerge additional root systems promoting decay. For serious root system penetrations in an earthen dam, decay increases the possibility of piping (FEMA, 2005, Pg. 4-11). Visible seepage may be seen around rootball cavities, indicating conditions susceptible to potential failure in the downstream embankment slope (FEMA, 2005, Pg. 4-11).

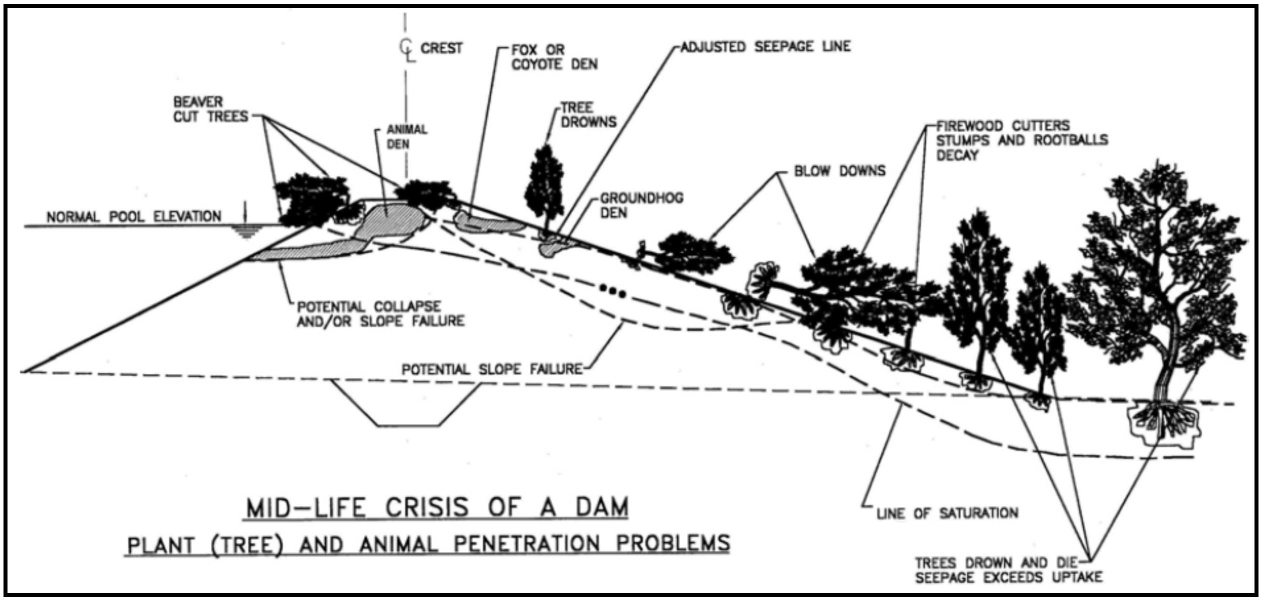


Figure 1: Mid-Life crisis of a Dam: Cross section of an earthen dam with significant tree growth, uprooted trees, cut stumps, and drowning root systems. Vegetation moisture uptake is reduced when trees are cut, blow down, or die. The line of saturation moves upward toward the downward slope, adjusting the seepage line, and increasing the potential for slope failure. (FEMA, 2005, Pg. 4-11).

<u>Tree Root Systems</u>

1. **Tree Root System Structure** - Tree and woody vegetation typically form a rootball “directly below the trunk of the tree to provide vertical support while the lateral transport roots provide lateral support for the tree” (FEMA, Pg. 3-5). On the uphill side of an embankment, lateral roots are relatively shorter and more horizontal (Figure 2); downhill roots tend to be larger and stay in upper soil horizons, restricted by the angle of the slope. Soil material and water availability are the main factors in determining root system structure, with specific tree species having limited influence (FEMA, Pg. 3-5 & Zanetti, et al., Pg. 1). Three common tree root structural groups or a mixture are typical; accompanying images of root excavations are presented in Figure 3.

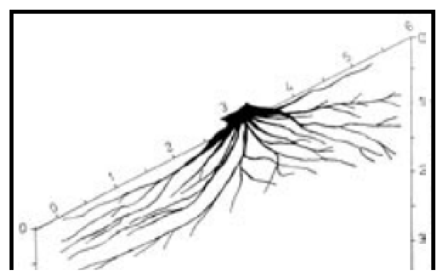
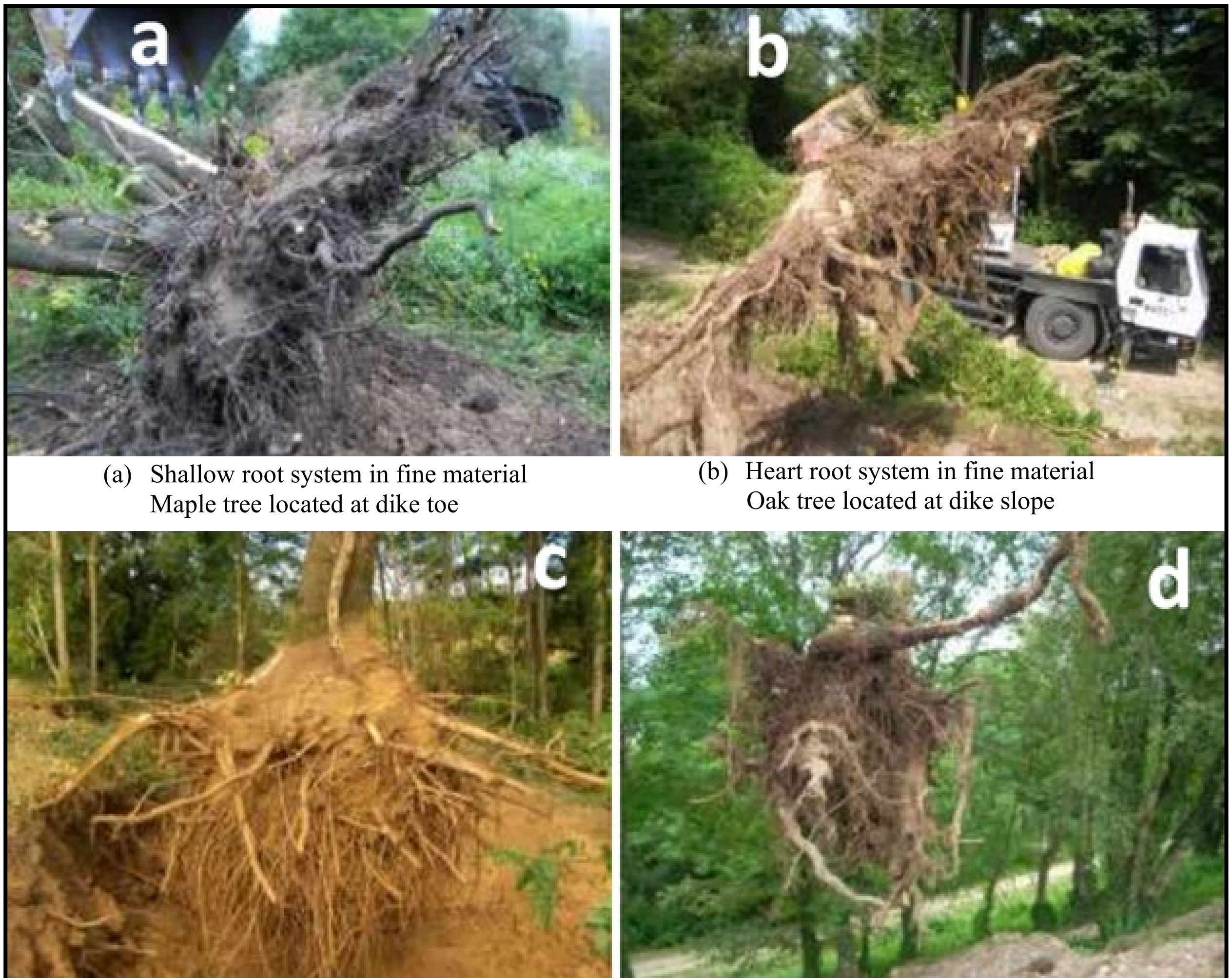


Figure 2: Root system along slope. (Mauer & Palátová, 2002, Pg. 347).

   a) Plate-shape root system, also called the shallow root system, in which all roots remain superficial.
   b) Heart root system, where roots occupy the whole space around the stump, with no preferential root angle.
   c) Mixed root system combining plate-shape and taproot systems, with two dominant root angles (vertical and horizontal) and no or few oblique roots.
   d) Taproot root system in which one single or a few large vertical roots dominate.



(a) Shallow root system in fine material
Maple tree located at dike toe

(b) Heart root system in fine material
Oak tree located at dike slope

(c) Mixed root system in coarse material
Poplar tree located at dike toe

(d) Tap root system in coarse material
Poplar tree located at dike slope

Figure 3: Four types of root systems typical around embankments. (Zanetti, et al., 2016, Pg. 6).

2. **Tree Root System Size** - The relationships of tree trunk size to root ball diameter and lateral transport root system diameter are presented in Table 1, copied from the FEMA Manual. The Manual does not outline the origins of the data; it is assumed that sufficient data was collected from a variety of tree species, located within relatively level and pervious or non-compacted soil conditions, which support these generalized ranges.

Table 1 - Typical Rootball and Root System Sizes for Various Tree Sizes. (FEMA, 2005, Pg. 3-5). Values converted from imperial to metric with rounding, as appropriate.

Typical Rootball and Root System Sizes for Various Tree Sizes		
Tree Diameter (cm)	Rootball Diameter (m)	Root System Diameter (m)
10 to 13	1.8	3.0 to 3.7
15 to 18	2.4	4.9 to 5.5
20 to 23	3.0	6.1 to 6.7
25 to 28	3.7	7.9 to 8.5
30 to 36	4.3	9.1 to 9.7
38 to 46	4.9	11.6 to 14.0
48 to 58	5.5	14.6 to 17.7
60 to 92	6.1	18.2 to 27.4
94 to 115	6.7	28.0 to 34.1

Compaction of embankment fill reduces air voids, limiting “the amount of surface water that can infiltrate into the embankment slope” (FEMA, 2005, Pg. 3-8). Research on 243 extracted root systems of mature trees on French dike fills resulted in the following summary (Zanetti, et al., 2016, Pg. 1):

a) Tree species had little influence on root system structure: all root system types and root size could be found for most of the species according to site conditions.
b) Heart root systems were limited to fine material.
c) Mixed and tap root systems were found on coarse material.
d) In coarse materials: trees developed few but rather large roots (> 5 cm in diameter and > 4 m in length).
e) In fine materials: root systems had three times more roots but they were 40% smaller and shorter.
f) Roots were 20% more numerous and 65% larger on the downslope side due to water availability at the dike or riverbank toe.

These results indicate that compaction may reduce root system size, root diameter, and/or root system spread, regardless of tree species.

3. **Tree Species Typical in Newfoundland and Labrador** - Fisheries and Land Resources identified 21 tree species which grow throughout the Province of Newfoundland and Labrador. A summary of root system characteristics for each species is presented in Table 2. Shallow roots are considered to be more susceptible to wind forces and have increased risk of blowing down, displacing earth from an embankment structure.

Vegetation-Free Zones

A range of dimensions have been recommended for tree and woody vegetation-free buffer zones around dams. These areas should be free of vegetation to limit the risks associated with extensive root systems and “provide access to and along structure for personnel and equipment for surveillance, inspection, maintenance, monitoring, and flood-fighting” (USACE, 2014, Pg. 2-1). The buffer zones are specific to individual documents. Areas have been delineated into at least one of the following (USACE, 2014, Pg. 3-3):

1. Dam and dam-toe area;
2. Areas in or around seepage monitoring systems, or critical downstream areas where seepage observation must be vigilant and continuous;
3. Groin abutments and areas immediately adjacent;

4. Spillways and spillway channels, including spillway slopes and approaches to spillways where vegetation could, in any way, impede the efficient operation of the spillway; and
5. The outlet-works discharge channel.

A summary of minimum vegetation-free zone areas outlined through various documentation is presented in Table 3. Sites with dimensions outside of the indicated ranges may be retroactively deemed acceptable based on site-specific limitations or as-built conditions. A typical cross section of the zones along a structure is presented in Figure 4.

Table 2 – Summary of the root systems for the 21 tree species which grow in the province of Newfoundland and Labrador.

Tree Species of Newfoundland and Labrador			
Common Name	Tree Type	Root System	Reference
American Mountain Ash	Deciduous	Combined: several stems	Mauer, O. & Palátová, E. (2002)
Balsam Fir	Conifer	Shallow: spreading	Frank, (n.d.)
Balsam Poplar	Deciduous	Combined: several stems	Zasada & Phippa, (n.d.)
Black Ash	Deciduous	Shallow: fibrous	Wright & Rauscher, (n.d.)
Black Spruce	Conifer	Shallow: within upper 20 cm (8 in)	Viereck & Johnston, (n.d.)
Choke Cherry	Shrub *	Deep: fibrous	Agiculture and Agri-food Canada, (2015)
Jack Pine	Conifer	Taproot; laterals: within upper 46 cm (18 in)	Rudolph & Laidly, (n.d.)
Mountain Alder	Shrub *	Shallow: spreading; More tree-like than Speckled Alder	Fryer, (2011)
Mountain Maple	Shrub *	Very shallow	Natural Resources Canada, (2015)
Mountain White Birch	Deciduous	Shallow; growth slower than White Birch	Safford, et al., (n.d.)
Pin Cherry	Deciduous	Shallow: spreading, within upper 61 cm. (24 in)	Wendel, (n.d.)
Red Maple	Deciduous	Taproot: short; Laterals: within upper 25 cm (10 in) of soil, may be 25 m (80 ft) long	Walters & Yawney, (n.d.)
Red Pine	Conifer	Taproot; Laterals: stout and wide spreading within upper 10 to 46 cm (4 to 18 in)	Rudolf, (n.d.)
Showy Mountain Ash	Shrub *	Shallow: extensive, does not tolerate compacted soil	Peronto & Manley, (2008)
Speckled Alder	Shrub *	Shallow: spreading	Fryer, (2011)
Tamarack	Conifer	Shallow: spreading, within upper 30 to 61 cm (12 to 24 in)	Johnston, (n.d.)
Trembling Aspen	Deciduous	Taproot; Laterals: shallow, extensive; Sinkers: within 3 m (10 ft)	Parala, (n.d.)
White Birch	Deciduous	Shallow: Mostly within upper 60 cm (24 in) of soil; Taproots do not form	Safford, et al., (n.d.)
White Pine	Conifer	Three - Five large roots spread outward and downward, vary with the soil characteristics	Wendel & Smith, (n.d.)
White Spruce	Conifer	Shallow: within 120 cm (48 in); Taproots; Sinkers; Most material within upper 0.3 m (1 ft)	Nienstaedt & Zasada, (n.d.)
Yellow Birch	Deciduous	Combined; Laterals: extensive, within upper 1.5 m (5 ft)	Erdmann, (n.d.)

* Shrub classification is interchangeable with 'Small Deciduous Tree'

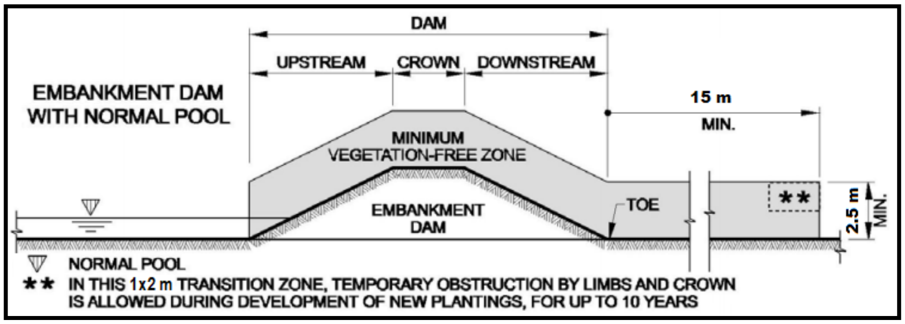


Figure 4 – Example of specific USACE Vegetation-Free Zone along an embankment dam. (USACE, 2014, Pg. A-16)

Table 3 - Measurements assumed to be taken from the outer edge of the outermost critical structure. USACE (2014) also identifies vegetation-free zone height of 2.5 m. Values converted from imperial to metric with rounding, as appropriate.

Vegetation-Free Zones and Dimensions	
Authority	**Minimum Distance for Vegetation Removal**
FEMA (2005)	Beyond downstream toe for half of the height of the structure
	Along entire dam structure
USACE (2014)	Beyond downstream toe for 15 m (50 ft.)
	Along appurtenant structures for 4.5 m (15 ft.)
	Along entire dam structure
New Hampshire Department of Environmental Services (2011)	Beyond downstream toe for 4.5 m (15 ft.)
	Along abutments for 4.5 m (15 ft.)
	Along entire dam structure
Hydro-Québec (Demers, et al., 2014)	Beyond downstream toe for up to 15 m
Nalcor (Dawe, P., personal communication, Sep 4, 2019)	Beyond downstream toe for 5 m
Finland (Laasonen, 2013)	Legislation allows vegetation which will not cause damage or harm to the maintenance or monitoring of the dam to remain along the dam structure

1. **New Vegetation Maintenance** - The only recommended form of vegetation within a vegetation-free zone is dense, uniform grass cover. Grass roots offer minimal penetration while combating surface erosion. Preference is given to regionally appropriate, perennial, and low-growing grass varieties. Routine maintenance reduces the encroachment of undesirable vegetation and increases visibility for inspections. A summary of minimum vegetation maintenance schedules outlined through various documentation is presented in Table 4. Control of non-grass vegetation is assumed to coincide with grass maintenance. Removal of weeds, tall grass, shrubs, trees, and woody vegetation should be performed before they have the chance to become established.

Table 4 - Grass Maintenance Schedule: Specific vegetation may require minimum maintenance which falls outside of identified requirements. Values converted from imperial to metric with rounding, as appropriate.

Grass Maintenance Schedule	
Authority	Minimum Requirement
FEMA (2005)	Twice annually
USACE (2014)	Once annually (ahead of inspection), except to keep grass height < 30.5 cm (12 in.)
ASDSO (2018)	Twice annually: late spring and after the growing season subsides
Hydro-Québec (Demers, et al., 2019)	Keep grass height < 15 cm

2. **Existing Vegetation Remediation** - Where vegetation other than an acceptable variety of grass has taken hold, some amount of remediation may be required. The significance of tree and woody vegetation growth is most beneficial when evaluated on a definitive scale with a consistent "evaluation methodology in order to prioritize the seriousness of various locations" (FEMA, Pg. 4-13). There is little consensus on parameters surrounding the removal criteria and procedure for mature trees or their established root systems.

   The impetus for rehabilitation begins "when effects of an improper vegetation maintenance and control program create conditions that are detrimental to the structural integrity of the earthen dam" (FEMA, Pg. 3-4). Young trees growing on a dam in British Columbia (Figure 5) were removed (Figure 6) before they could become established and threaten the structure.

Figure 5: Before Remediation: excess growth, broken log boom. (FEMA, 2005, Pg. 34).

Figure 6: After Remediation: Properly maintained crest and embankment. (FEMA, 2005, Pg. 34).

Detailed remediation design criteria are outlined in the FEMA Manual and form the basis for most American policy. A summary of specific removal criteria is presented in Table 5. Some literature refers to "*small* and *large* trees, where the definition basis ranges from two to eight inches in diameter" (measured at breast height); most use a size of four or six inches to delineate between what is considered a small versus a large tree, to carry out their policies (FEMA, Pg. 2-6).

All authorities outlined in Table 5 recommend some form of vegetation removal. However, it may be beneficial to retain trees on an embankment dam at some sites. Decomposition of long, thick roots could cause piping and eventual failure of the structure, but existing "vegetation is sometimes tolerated due to access difficulty and safety issues for workers on steep slopes" (Demers, et al. 2019, Pg. 1975). Where trees are retained, selective trimming may be used to "keep them alive but not grow any further" (Oskoorouchi & Lane, 2004, Pg. 3).

Table 5 - Vegetation Removal Criteria: Summary of various limits for tree size or diameter. Some criteria are further classified to be location-specific on a structure (D/S refers to Downstream and U/S to Upstream). Lowering of a reservoir may be required. Values converted from imperial to metric with rounding, as appropriate.

Vegetation Removal Criteria		
Authority	**Size or Diameter**	**Remediation Action**
FEMA (2005)	All U/S Slope Trees	Remove entirely, including rootball & roots*
	Crest Tree > 30 cm (12 in.)	Remove entirely, including rootball & roots*
	D/S Slope Tree < 20 cm (8 in.)	Cut and seal to delay decay
	D/S Slope Tree > 20 cm (8 in.)	Remove entirely, including rootball & roots*
	Dam Toe Tree < 10 cm (4 in.)	Cut and seal to delay decay
	Dam Toe Tree > 10 cm (4 in.)	Remove entirely, including rootball & roots*
USACE (2014)	Tree within 5m (15 ft.) of structure	Remove entirely, including rootball & root system
	Tree outside 5m (15 ft.) of structure	Remove entirely, including rootball & roots*
ASDSO (2018)	Small Tree	Remove entirely, including rootball
	Large Tree	Grind stump 15 cm (6 in.) below ground surface
	Tree within riprap	Cut and chemically treat to prohibit new growth
Hydro-Québec (Demers, et al., 2019)	Tree stump	Remove entirely, including rootball
	Roots > 50 mm	Remove entirely
	Interwoven roots < 50 mm	Remove entirely
	Other woody vegetation	Cut to < 150mm above ground surface
Finland (Laasonen, 2013)	When Deciduous Tree is Cut	Remove entirely, including rootball & root system
	When Pine Tree is Cut	Remove stump to ground surface

*indicates removal of roots >1.3cm (½in) only

In Finland, selective maintenance in specific areas allows established "trees to grow bigger [in order to] reduce new growth of bushes and the related maintenance costs" (Laasonen, 2013, Pg. 1). For cases where trees are allowed to remain, routine inspection becomes critical; "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" (FEMA, Pg. 4-9). Following a Finish review of previously cut stumps, deciduous trees were found to be far more likely to deteriorate, and it was recommended that deciduous tree and root systems be fully removed when the tree was cut. Conversely, the conifer tree stumps removed had no visible signs of rot and it was determined that they "may be left, if they are situated in the upper part of the slope" (Laasonen, 2013, Pg. 4).

Figure 5 - Stump Pull Test: Removal of Alder stump at Peltokoski embankment dam, Finland. Image retrieved from (Laasonen, 2013, Pg. 2).

Figure 6 – Eucalyptus tree root system within embankment slope exposed Image retrieved from (Shriro, et al., 2013, Pg. 97)

Figure 7 - Seepage caused by piping through a dam's embankment. (United States Department of Agriculture, Pg. 13).

The removal of a rotten tree stump by pulling (Figure 7) causes breakage of roots at weak points. Careful extraction of an embankment slope (Figure 8) exposes a decaying eucalyptus tree, indicating the possible size and spread of a shallow root system. Where woody vegetation has been previously removed, there may be a need for additional remediation. In Illinois a downstream slope "failure initiated from decomposition of the roots of several grown trees previously cut-down" (Oskoorouchi & Lane, 2004, Pg. 2). Once a tree dies, the root system should be removed and the structure backfilled to "restore this dam to a safe condition and original design life" (FEMA, Pg. 4.11).

Proper documentation of site observations during routine inspection allows comparison with historical records; changes in the site can be easily identified and communicated to decision makers. Inspectors are encouraged to be diligent in investigating: vegetation which appears stressed; any areas of discoloration on the ground; or unexpected seepage (Figure 9) (Ontario Ministry of Natural Resources, 2011, Pg. 5).

Conclusion

The decision to remove trees and woody vegetation from earthen dams is a dam safety and performance issue. The FEMA Manual (2005) forms the basis for many existing vegetation control policies, but no singular set of criteria and remediation methods have been universally accepted.

Tree and woody vegetation on earthen dams will continually loosen soil through root penetration. The review of earthen dam vegetation against a standard set of criteria can establish when, and to what extent, remediation activities may be required. The majority of documentation suggests that trees be removed from vegetation-free zones to mitigate risk. There is no consensus, however, on the method of removal or minimum volume to remove (tree trunk, rootball, roots >1.3 cm only, and/or the entire root system).

There may be negative future impacts from inadequate tree removal; leaving root systems to decompose in-place increases the likelihood of piping. Where removal of mature trees is not possible due to site conditions, it may be beneficial to adapt a maintenance regime that restricts root system expansion. Vegetation is recommended to be maintained at-least annually, with all tree and woody new-growth removed from low-lying grass areas.

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