Burrowing Activity of Muskrats, Nutrias and Beavers on River Levees – Damages, Consequences and Mitigation Measures

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Abstract: Flood risk analysis is an essential part of modern flood risk management. For riverine areas that are mainly protected by levees, the inundation risk derives from the possibility of levee failure. Failure occurs if the loads on the levee exceed its resistance. Both load and resistance characteristics of a levee are influenced by its local properties. Rodents like muskrats, nutrias or beavers can change a levee's properties rapidly due to their burrowing activities. Thus, a levee's stability can decrease considerably. Hence, investigations regarding a levee's infestation by burrowing animals can be a crucial task in modern flood risk analysis. On this background, general characteristics and aspects regarding the infestation of river banks, forelands and levees by muskrats, nutrias and beavers are presented with focus on experiences and regulations in Germany. Based on the biological characteristics of the three species, typical damage features and negative consequences are described and a brief overview regarding recent surveys and investigations is given. Furthermore, technical measures for protecting levees against burrowing activities as well as techniques for detection of underground cavities in earthen materials are presented.

Keywords: Levee; stability; flood risk, burrowing animals; measures.

1 Introduction

Based on the EU Water Framework Directive and the EU Floods Directive, all member states of the European Union are required to achieve a 'good ecological status' for water bodies (or at least a "good ecological potential" if heavily modified) in their responsibility. In this regard, the restoration of rivers is currently one major and challenging task, since the transformation of rivers into a near natural state also promotes biological impacts that may lead to an increased flood risk. Beside an increased vegetation growth in and along a river leading to retardation and retention of flood waves, the activities of animals can influence the function and reliability of technical flood mitigation measures considerably. This holds particularly true for river levees, which are vulnerable to burrowing activities of animals being earthen structures. As Germany is located in the northern temperate climate zone the most common species populating river levees (permanently or temporarily during floods) are e.g. mole, mouse, fox and rabbit. Moreover, large rodents such as muskrat (*Ondatra zibethicus*), nutria (*Myocastor coypus*) and beaver (Eurasian beaver – *Castor fiber*, North American beaver – *Castor canadensis*) being the second largest rodent worldwide, cause major problems in many middle European rivers. On this background the characteristics of the latter species (muskrat, nutria, beaver), relevant damages, possible effects on levees as well as selected mitigation measures and management issues will be presented and discussed in more detail in the following sections.

2 Biological Characteristics

In order to identify and evaluate possible measures against damages at river banks and levees caused by muskrats, nutrias or beavers the biological characteristics of these species need to be considered. Since the beaver was almost completely eradicated in Middle Europe at the end of the 19th century, it is nowadays a protected species in many European countries and beaver hunting is prohibited. Due to this in combination with the relocation of beavers, the population of both subspecies, Eurasian and North American beaver, recovered considerably during the last century in Europe. Today, the beaver population is estimated to 30.000 in Germany and to about 1 million in Europe (LfU 2015).

In contrast, muskrat and nutria are classified as invasive species in Europe. Hence, they do not have a protection status in Europe and population control through hunting is possible. In Fig. 1 the appearance and proportions of all three species is compared. Table 1 contains characteristics that are most relevant for the identification of the species.

Proceedings of the 7th International Symposium on Geotechnical Safety and Risk (ISGSR)
Editors: Jianye Ching, Dian-Qing Li and Jie Zhang

Published by Research Publishing, Singapore.
ISBN: 978-981-11-2725-0; doi:10.3850/978-981-11-2725-0_IS4-8-cd

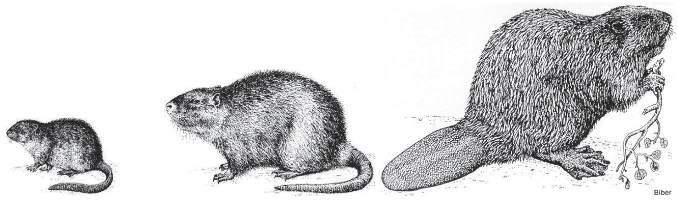


Figure 1. Appearance and proportions of muskrat (*Ondatra zibethicus*), nutria (*Myocastor coypus*) and beaver (*Castor fiber*) (source: DWA-M 608-1, 2017; drawings by F. Müller)

Table 1. Characteristics of muskrat, nutria and beaver

Properties (adult)		Muskrat	Nutria	Beaver
Weight	[kg]	< 2	< 10	< 30
Length	[m]	< 0,70	< 1,10	< 1,30
Tailshape		round, circular	round, circular	flat, oval

3 Conflicts and Damages in River Basins

There is no doubt that all three rodents help to improve the ecological status of rivers and increase morphological heterogeneity and biodiversity since they are able to create and alter habitats according to their needs. This holds particularly true for the beaver who can even generate wetlands by building dams. On the other hand, the activities of the rodents can lead to various conflicts and damages in cultivated landscapes, which are mainly

- undermining of natural surfaces and technical structures (roads, rail tracks, levees),
- sediment input and blocking of ditches,
- clogging of pipes and culverts,
- crop losses,

and more typical for beavers

- land loss through flooding
- tree cutting.

a) Muskrat damage in river bank (source: DWA, 2017)
b) Beaver damage in river foreland (photo: F. Krüger)
c) Beaver den in levee (photo: F. Krüger)

Figure 2. Damages caused by muskrats and beavers along rivers

With regard to river management issues, rodent burrowing activities in particular cause damages since tunnels, galleries and dens can destabilize banks, forelands and levees considerably. This leads to serious river maintenance and flood risk management problems. Van der Steen (2018) considers e.g. muskrat control as an "existential challenge" for the Netherlands (total area: 42.508 km²) and mentions annual expenses of 33,5 Mio EUR for muskrat and 1,2 Mio EUR for nutria control only. According to Schütz (2016), the German federal state of Brandenburg (total area: 29.479 km²), quotes the specific expenses for controlling the rodents (including technical mitigation measures) to be:

- Muskrat: > 528.296 EUR/year,
- Beaver: > 137.110 EUR/year,
- Nutria: > 136.612 EUR/year,

with an expected growth in the financial demand during the next years.

4 Surveys and Analysis

Due to the increasing problems and damages in river basins caused by the considered species, numerous surveys and studies were recently conducted worldwide. FEMA (2005) investigated the impacts of animals on earthen dams systematically, and the major effects were categorized as

- hydraulic alteration (alteration of seepage behavior)
- structural integrity losses (structural instability of tunnels and dens; in case of collapse: loss of freeboard)
- surface erosion (decreased erosion resistance of grass cover)

Cobos-Roa (2015) examined the impacts of vegetation and burrowing animals on levees in the United States. Beside a detailed description of several levee failures caused by burrowing activities he also presents survey results, where tunnel and den systems were visualized and geometries quantified through grouting and subsequent excavation. Furthermore, a systematic survey of burrows on levee surfaces is presented there (Fig. 3).

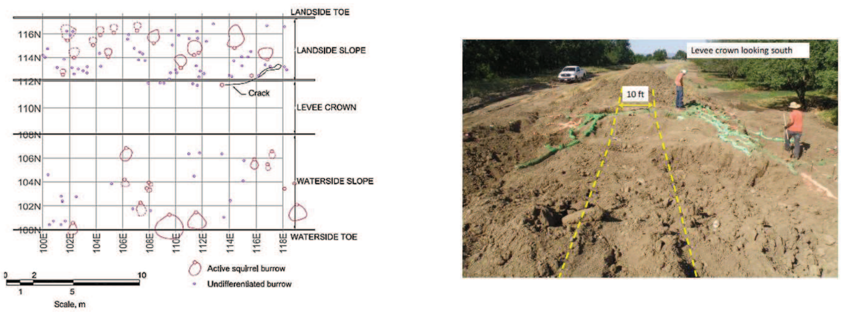


Figure 3. Survey of burrows (squirrel) on levee surface and identification of a tunnel-den-systems through grouting (source: Cobos-Roa 2015)

In physical and numerical model tests, Saghaee et al. (2017) studied the effects of levee inhomogeneities (horizontal cavities on the land- and on the waterside) and proved the negative consequences for the seepage behavior and the stability of selected levee setups. In conclusion, they state an average safety factor reduction of about 25% for the investigated cases of waterside, mid-height burrows in levees with 1:1,1:2 and 1:3 slopes. Pennisi et al. (2018) started similar investigations based on physical model tests accompanied by 3D numerical simulations.

At the Technische Universität Dresden (TU Dresden) first surveys regarding levee intrusion by burrowing animals started in 2012 by means of a video-camera inspection (Fig. 4) of a beaver tunnel in a river levee, which was discovered shortly after a flood event. The tunnel entrance was located about 1 m below the maximum flood water level. Showing a mild upward gradient, the tunnel with a diameter of about 0,3-0,4 m reached about 3m into the levee ending in a den with a diameter of about 1 m. In order to quantify dimensions and shapes of such beaver tunnels in more detail, similar inspections are planned for 2019 using (rotating) laser scanning technology.

Figure 4. Video-camera inspection of a beaver tunnel in levee at River Oder near Neurüdnitz (Germany)

Subsequently, surveys concerning the relevance of levee infestation by burrowing animals with regard to flood risk analysis were done at TU Dresden by Clauß (2013), Alshomaree (2014) and Schütz (2016). By conducting 2D numerical sensitivity analysis regarding the effect of water- and landside tunnels on homogeneous and zoned levees (steady state conditions) it was found that:

- for waterside tunnels:
  - phreatic line with tunnel on waterside is higher than in reference state (no tunnel)
  - exit point of phreatic line on landside slope is equal or higher than in reference state
  - burrowing damage in zoned levee (penetration of surface sealing) leads to greater stability reduction than in homogeneous levees; thus, zoned levees are more vulnerable against impacts by burrowing animals
  - increased seepage rate
- for landside tunnels:
  - tunnels on the landside lower the phreatic line due to drainage effect compared to reference state (but tunnel erosion and collapse may occur)
  - exit point of phreatic line on landside slope is equal or lower than without tunnel
  - increased seepage rate

5 Detection of Tunnel Systems and Dens

As cavities in levees decrease its stability, the detection of tunnel and den systems prior or during floods is of crucial importance. Since the entrances to the burrows are usually submerged, visual inspections or random penetration tests will not lead to success. With the aim of detecting the entrances to muskrat tunnels in river banks from the waterside, Van der Steen (2018) reported about the successful use of boat-mounted sonars, with a hit ratio of about 70 %. Bayoumi and Meguid (2011) mention the following techniques that may be applied for cavity detection in earthen dams

- gravity survey
- resistivity methods
- seismic reflection
- ground penetration radar (GPR)

They conclude that the GPR is the best method for identifying animal burrows in earthen structures. However, as reported from an in-situ test for tunnel and den detection using GPR along the Oder River in Brandenburg (Germany), the method did not lead to the desired result as it failed to detect water filled voids in particular. Since the identification of water-filled voids is particularly relevant for beaver, muskrat and nutria, further investigations regarding suitable detection techniques are planned for 2019, also accounting for aspects of reliability and applicability.

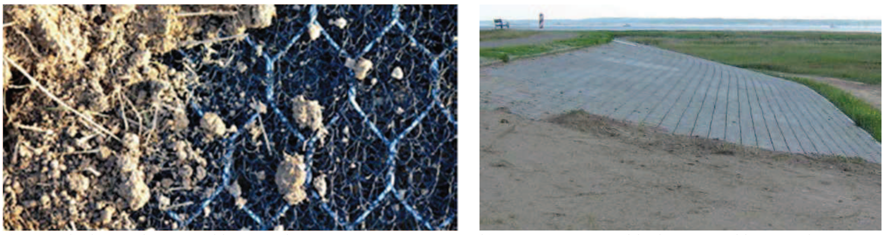
6 Mitigation Measures and Management

As mentioned earlier, the burrowing activities of muskrat, nutria and beaver can lead to a considerable decrease in levee stability and thus to high economic damage. Furthermore, tunnel and den systems in river banks pose a serious hazard to river maintenance workers. For this reasons technical and non-technical measures must be taken. Non-technical measures include population control e.g. by hunting and trapping of muskrats and nutria. One of the most sophisticated strategies for muskrat population control was developed in the Netherlands (Van der Steen 2018). Depending on the characteristics of every region, different approaches of hunting and trapping strategies were developed and are updated continuously, also for the purpose of prioritization. For this reason, a mobile app is used that allows for recording and analyzing of regional catch statistics. Since the beaver is a protected species in many European countries, including Germany, beaver hunting is allowed in exceptional circumstances only. Thus, regional beaver managers in the whole of Europe cooperate in order to redistribute and resettle beavers.

Regarding the technical measures, and with particular focus on technologies that prevent burrows in river banks and levees, basically any technology is suitable that creates a barrier against burrowing action. Regarding solutions that function mechanically the following criteria should be fulfilled:

- sufficient (small scale) resistance against animal impact (biting and digging forces)
- high (large scale) resistance against other mechanical impacts (currents, turbulence, ice drift etc.)
- high durability
- high flexibility
- promotion of rooting (grass cover)
- no/low disturbance of maintenance works
- low environmental impact (short and long term)

Based on this criteria, regular bioengineering measures (e.g., wattle work) or geosynthetics are not suitable, as their resistance against rodent bites is insufficient. Fig. 5 shows two possible solutions for burrowing protection at levees in Germany. Until today, both technologies, coated wire meshes (see e.g., Arndt 2015) and pre-cast concrete blocks, show good results and reinforced levee sections have not been damaged by rodents or other burrowing animals. Other technical solutions are e.g. riprap zones, sheet pile walls (steel or synthetic material) or diaphragm walls.



a) Coated wire mesh, covered by grass layer (source: Maccaferri, "MacMat"®)

b) Pre-cast concrete blocks, covered by grass layer (source: Berding Beton, „Aqua-Verkalit"®)

Figure 5. Examples of mechanical barriers against animal burrows on levees

Beside the materials and structures being used for burrowing protection an appropriate design, placement, and installation is also important. Regarding the placement of mechanical barriers, Fig. 6 summarizes general possibilities. Depending on the specific site characteristics (rodent species, floodplain and levee dimensions, damage potential in the hinterland) all solutions can be implemented separately or in combination.

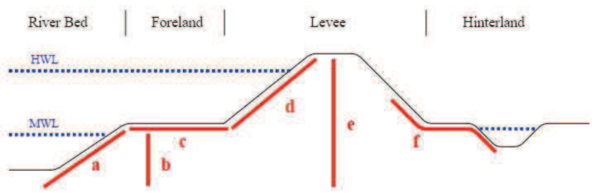


Figure 6. Possible locations for mechanical barriers against animal burrows on and in levees

From experience gathered in Germany the following design principles should be followed:

- base of barrier (e.g., riprap) at least at river bed level (or below), should reach up to foreland level
- base of vertical barrier (e.g., coated wire mesh) at least at river bed level (or below), should end about 20-30 cm below foreland level (river maintenance)
- implementation only reasonable in combination with a) or b) and d) or e); 10-20 cm cover layer (surface soil) required (grass cover)
- barrier (coated wire mesh, pre-cast concrete blocks or similar) should be founded below foreland level, 10-20 cm cover layer (surface soil) required
- vertical barriers (e.g., sheet pile walls) should end below foreland level, can be designed as self-supporting structure to increase overtopping resistance
- might be relevant, if landside toe of levee is submerged (e.g., through ditch) over long periods; sufficient drainage capacity of landside levee toe must be ensured

Regarding the construction of the barriers, special attention must be paid to the joints and overlaps of the individual elements used. Furthermore, it must be considered that the rodents will migrate to adjacent levee sections with no burrowing barriers, which can be accepted if an overall flood risk reduction is nevertheless achieve. Due to the many factors that need to be considered it becomes obvious that there is no standard solution for training levees against burrowing animal action. Thus, a site specific design is required that also includes considerations regarding the long term effect for adjacent levee and river areas.

7 Conclusions and Perspective

Due to the requirements of the EU Water Framework Directive and the EU Floods Directive to improve the ecological status of all water bodies without increasing flood risk, investigations regarding biological impacts on levees are of increasing importance. The burrowing activities of muskrats, nutrias and beavers are particularly relevant for rivers and levees in Germany. Extensive tunnel or tunnels systems and large dens can lead to a considerable reduction of a levee's stability and will increase flood risk in rather short time. Moreover, tunnel systems in banks and forelands of rivers pose a serious hazard for river maintenance works. Several research topics emerge from these facts, such as the detection of air- or water-filled cavities or the development of effective and ecologically sound mitigation measures and management strategies. New measuring techniques and instruments allow for a more comprehensive monitoring of biological impacts and the corresponding levee behavior in the near future, which can in turn lead to an improved and site specific design and maintenance practice for river levees. Finally, the extended knowledge about damages caused by burrowing animals needs to be included in levee reliability analysis and flood risk assessment. Since the sudden collapse of tunnels or galleries is expected to influence a levees performance during floods most significantly, the simplest way to account for burrowing animal impacts quantitatively could be an assumed freeboard reduction by one diameter (or a multiple thereof) of a species-specific tunnel along the infested levee section. More sophisticated approaches for integrating biological influences in flood risk analysis are subject of current research.

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