

# **ENVIRONMENTAL PROTECTION OF HEAVY WEAPONS RANGES: TECHNICAL AND PRACTICAL SOLUTIONS**





## PREFACE

Requirements of environmental legislation and enhanced understanding of environmental impacts of military training have highlighted the need for developing environmental protection on shooting and training areas. Although legislation and practical requirements vary from country to country, there is a global trend of increasing expectations towards defence authorities in the area of environmental protection.

Extensive research on relevant issues concerning key environmental impacts of heavy weapons shootings has been conducted in several countries. Sharing information and knowledge is essential to fill the gaps within the knowledge base of different countries and to save time and resources.

To answer these elevated expectations, an international project was launched in 2016 on the initiative of Finland. The project's prime goal was to gather existing data of environmental aspects on heavy weapons ranges and to assess, describe and recommend possible methods to manage environmental impacts. One goal was to achieve a process to assess and design the sufficient level of environmental protection at actual sites.

The participants in the project included environmental and legal experts from the defence administrations of Finland, Sweden, Norway, Denmark, the United States and Canada. From Finland there were also environmental authorities and specialists from other government agencies. Importantly, the project organizers recognized that more than environmental expertise alone was necessary. In order to define genuinely feasible solutions, the possibilities and limitations in developing training practices must be understood. For that purpose, experienced military officers were included in the project.

The Nordic countries have a long history of cooperation and information exchange in the environmental field. Within the Nordic Defence Estate –cooperation forum, a permanent working group for environmental issues was established already in 2004. In 2015, the cooperation broadened to include the Baltic countries as well. The Nordic-Baltic Defence Estates (NBDE) –cooperation forum's Working Group Environment has formed the backbone of the Environmental Protection of Heavy Weapons Ranges project organization, by coordinating the use of resources from the participating Nordic countries, and providing a network of specialist in defence related environmental issues.

A list of participants is in Appendix 1A. It should be noted that the content of this document does not reflect the policies or programs of their respective governments.

## Executive Summary

Military training with heavy weapons has several impacts on the environment; these impacts can be either temporary or lasting. During training itself, the use of heavy weapons generates noise. One of the long-term effects of training are the traces of explosives and other contaminants left in the soil and groundwater. Training activities may also negatively affect nature in the area, including flora and fauna. However, it can also be noted that certain species actually benefit from military activities; for example, pioneer species need burnt terrain to thrive. Contaminated soil or water as well as noise can further have harmful effects on nature or people. There are also direct physical impacts such as dust, soil condensation and burning.

Armed forces are expected to fully meet the requirements of environmental protection. Due to the tightening legislative requirements combined with an enhanced understanding of the environmental impacts of military training there is an increased need for more standardized technical solutions and management practices on shooting and training areas. To better facilitate future international cooperation, environmental protection schemes should be more uniformed and take into account specific needs that visiting troops or those training together in multinational coalitions may have.

The project's prime goal was to gather existing data of environmental aspects on heavy weapons ranges and to assess, describe and recommend possible methods to manage environmental impacts. One goal was to achieve a process to assess and design the sufficient level of environmental protection at actual sites.

The project focused on the full range of environmental aspects of heavy weapons training. It covered noise management, nature and cultural heritage management and contaminant management. The content focuses on these three topical areas:

- environmental impacts caused by heavy weapons training,
- practices and technologies which could be used to might mitigate some of these impacts,
- recommendations for the impact management and the topics for further study and development.

In order to manage environmental impacts of shooting and training activities on military ranges, one must first understand the impact mechanisms, emissions and the significance of the impacts specific to a given site. With this information, a decision about the need for further measures can be made. After the initial assessment, further surveys, modelling and more detailed risk assessments may be needed before the correct level of risk management and feasible methods can be chosen.

It is important to have a conceptual model to help assess the environmental impacts on a certain range. To form a Generic Conceptual Model (GCM) all the activities that may have an effect on the environment are drawn on a map or a generic picture of the area. With the GCM it is possible to identify the possibly sensitive environmental compartments and to decide the focus area(s) for further assessment.

The next step is to list all the training activities in a simple table and identify the possible primary impacts they may have on the environment. At this point there is no need to assess transport routes or secondary impacts on humans and environment. The primary impacts are noise, dust and air emissions, contaminants, disturbance on soil and direct impact on flora and fauna.

One of the most significant environmental impacts of training on heavy weapons ranges is noise. Noise can cause annoyance and, in the worst case, negative health effects. For a heavy weapons training area operator, the main risk is annoyance due to noise. This may lead to a conflict with surrounding communities and eventually to limitations of training opportunities by e.g. strict environmental permit conditions.

Noise from heavy weapons is different from other types of environmental noise. It is impulsive by nature and it has different frequency characteristics than, for example, traffic noise. Noise is created in different ways in different phases of the shooting event. Emissions can be divided into the blast, projectile noise and impact (explosion) noise.

Vibration and rattle are also associated with heavy weapon shootings. Vibrations occur both in the ground and inside a building. Reducing vibrations from low frequent sound in the building is best achieved by reducing the noise itself. In extreme cases the largest explosives or larger propellant charges of the heaviest cannons may excite actual vibration in buildings, for instance in floors or walls. Vibrations from explosions can cause damage to the foundation of a building, but this requires much higher vibration levels than can usually exist in the housing areas surrounding heavy weapons training areas.

The spectrum of an explosion usually contains more low frequency sound than from the confined explosion of a gun. Humans do not perceive low frequencies, as the sound level is relatively high. Wood frame houses and windows respond to the low frequency component of the sound with rattles and vibration. The low frequency sound waves from explosions propagate over much longer distances than the sound waves of higher frequency.

The environmental authorities commonly give noise regulations in the form of noise guidance or limit values and/or restrictions on operation hours. In order to reduce the risk

of having unwanted restrictions on military training areas, the noise risks of heavy weapons training should proactively be determined. For identifying the risks of noise produced by heavy weapons training, a detailed knowledge of the training area, noise emissions, training activities, geography and nearby communities is essential.

Most favorable and effective noise mitigation methods usually used for environmental noise, such as reducing noise emissions, are not applicable to training with heavy weapons. For reducing the effects of noise from heavy weapons training, several noise mitigation or management methods are needed simultaneously. Land use planning is an effective tool in noise management, especially in the long term. If noise areas of heavy weapons training are taken into account in land use planning, it will prevent building of new housing or other noise sensitive facilities close to areas where noise from training activities exist. Planning of heavy weapons training schedules can be an effective way in reaching noise management objectives. Training should be scheduled so that most noisy activities are performed at daytime on weekdays. Weather conditions have a major influence on sound propagation. Therefore, it is possible to reduce noise exposure by ensuring that the activities are completed mainly on days where weather conditions are least favorable for sound propagation. While changes in daily weather conditions can usually not be taken into account when planning training, it is possible to plan training taking into consideration typical seasonal weather phenomena.

A registration system is necessary to monitor the use of the ranges and to document to the authorities that the scope for planned activities and activity-free periods are not exceeded. Input to the registration system is used type of ammunition, site and date.

There have been several good experiences of using different methods of communicating with local communities near training areas. Training calendars and information about training events can be announced in local papers, billboards near the ranges and on the internet. A feedback system where people can express their views and can report or even discuss noise disturbance related to training activities can be effective ways to mitigate the noise problem. Some of the countries have very good experiences with planning a long-term activity schedule and publishing it once or more a year.

Since noise from heavy weapons is dominated by low frequencies, noise attenuation using noise screens has only a minor effect and the screens need to be placed close to the noisy activities or neighbors. Noise screens are therefore not appropriate when the noisy activities are distributed over a larger area. At smaller activities with fixed positions, noise screens can be a solution to achieve noise reduction. Berms or pit walls can also reduce noise with smaller explo-

sions but are usually negligible when the mass of explosive charges are 5-10 kg or larger.

Military training may have considerable impacts on the nature values and cultural heritage of the training area. Impacts are often negative, but there may be some positive effects as well. Areas disturbed by fire, heavy vehicles or grenades, for example, provide suitable living conditions for some species. The impacts are site-specific and their importance needs to be evaluated for each area and situation. Cultural artifacts may also be present in the terrain. The challenge is thus to maintain the unusual conditions of the military training areas and still be able to use these areas for their main purpose.

In general, long-term heavy weapons training changes habitats at the site, usually creating open habitats because of frequent physical disturbance. Impacts can be direct or indirect. Erosion caused by heavy vehicle maneuvering and target area explosions are examples of direct effects. On the other hand, contamination of soil and water, human presence and noise could have indirect impacts on nature values. In addition, keeping the military areas open for the training reasons exposes the areas to invasive species, which needs to be recognized and controlled.

Risk assessment of cultural heritage values begins with analyzing the likelihood of presence of culturally significant artifacts on the terrain. If there is a strong likelihood of finding artifacts, a contingency plan for accidental discovery can become of use and a more detailed study should be undertaken. Based on the study, protection measures should be planned. These include map markings, safety zones on maps and instructions such as no-go zones possibly demarcated by poles or signs. A contingency plan should be formulated and communicated to key personnel.

A process, that includes baseline study, impact analysis and risk assessment, mitigation and compensation planning, action plan, monitoring and reporting, is suggested for integrating nature and cultural heritage values into the management of shooting and training areas. When looking at best practices relating to the management of military training areas, it is not possible to make generic, but specific instructions. The chosen practice must always be found through a planning process that takes into account the particular area in question and the particular military need. It is important to take an ecosystem-level approach in the management of military training areas that integrates soil, water, noise and forest issues.

In order to prevent noise impact to nature values, it is important to avoid noise during vital periods (e.g. nesting times) and sites (hibernation areas, vital nesting sites). When changing the training areas by physical disturbance,

it is important to evaluate the size, timing and duration of the disturbance. When building new structures the project must be evaluated according to the regulations for the area. The administrators of the training areas should spend considerable time deciding the location of target areas. These evaluations should include whether the areas should be smaller and more intensely used or bigger with less intensive use. If possible, rotating the target areas can give the plants time to spread to the exploded area, while another area is used as the target area. Many conditions influence the amount and distribution of invasive species. Norwegian defense authorities have developed their own guidelines for transport of military equipment in and out of the country. In order to keep training areas open, human efforts have to replace what has traditionally been done by cows, sheep and goats through their grazing practices or by wild fires. A management plan for the area that is meant to be kept open is needed to target the overgrowth. Range managers should receive appropriate education on the values of biodiversity, including mitigating techniques to minimize negative impacts. Land users should receive appropriate education or information in order to promote course of actions that minimize the negative impacts on natural and cultural resources. Permanent information boards concerning the natural and cultural resources, as well as desirable behavior, may be installed at the gates of the military training areas. Temporary signs can be installed when extra caution is required in certain areas during specific time periods (e.g. breeding periods and nesting). Restoration of the natural water balance may benefit both biodiversity and military use.

Training with live munitions involves the use of many potentially contaminating substances: metals, pyrotechnics and obscurants, and energetic materials such as propellants and explosives. These substances may transport from contaminated soil to groundwater or surface water. Contamination levels on ranges are a sum of many factors: the efficiency of weapon systems and munitions, level of exposure and also temporal factors. Intact unexploded ordnance (UXO) is a potential long-term point source, whereas a low-order or partial detonation releases a significant amount of energetics into a small area causing more immediate effects.

The nature and extent of contamination from training with military munitions varies based on several factors. The weapon system is obviously important, as is the type of training involved. For example propellant residues from anti-tank, rocket, and missile weapon systems will be behind the firing position rather than in front. The most highly contaminated ranges are demolition ranges due to unconfined detonations. Disposal of excess propellants, if done improperly, may be highly contaminating. Training on demo ranges also has the potential for high concentration of contaminants, especially as most of the explosives used will be unconfined.

Ranges with fixed firing positions will have more concentrated areas of propellant residues compared to maneuver ranges because of fixed firing positions at qualifying range. Impact range contamination distribution patterns are dependent on target arrays and mode of fire. Direct fire ranges have concentrated fire on a small number of targets. Indirect fire ranges have targets scattered around a large area. To effectively manage a range for environmental protection, it is critical to know what is being fired into a range and how it is detonated. Insensitive munitions are a source of emerging contaminants on training ranges. Current insensitive munitions have been shown to be less efficient than TNT or Comp-B rounds during detonations.

All heavy weapons munitions and some propellants contain metals (Al, Pb). Most of the metal in a projectile is either iron or aluminum, which are commonly occurring elements in the soil. However, some munitions, especially older munitions, rockets and missiles may contain more toxic heavy metals. The metals deposited on ranges will initially be in two forms: fragments (or intact sections of munitions) and fine metallic debris. The larger fragments, munitions parts, and UXO are relatively easy to clean up if access to a range is feasible. Fine particulate metal and metallic dust are not. Metallic dust is the result of the use of penetrators and shape charge munitions. The metals involved (copper, tungsten, nickel, and uranium, among others), are extremely toxic when inhaled or ingested. An acidic environment may mobilize metals, and a wet environment can facilitate the transport of metals to groundwater. Shaped charges and cargo ammunition (cluster munition) contain copper. High concentrations of lead have also been observed on sites, where small arms ammunition is destroyed.

Pyrotechnics and obscurants are commonly used on training ranges, either as dedicated rounds (smoke rounds, flares) or as components on direct-fire munitions (tracers). They contain various metals and oxidizers. Many pyrotechnic devices contain perchlorate; the largest threat of contamination would be from improper disposal of excess pyrotechnic devices. White phosphorus is a pyrophoric element used as an incendiary and an obscurant. White phosphorus is extremely toxic in the environment. Because of its toxic properties, the use of white phosphorus is avoided in several countries.

Guidance values are useful for environmental maintenance of a site and decision making. Emissions caused by military training can be monitored and controlled by referring the resulting emissions to substance-specific guidelines. Guidance values can be assessed to low threshold level, or they can be set to represent the highest acceptable concentration of the substance. Also, a guidance value may indicate the chemical concentration of individual analyses, or it may mean the annual average of the chemical load into the receiving water body. Therefore, when selecting guidance values for range management purposes, the funda-

mental objectives of the guidance values as well as the site management goals must be clearly understood.

In short, for health and/or ecological risk to occur, three fundamental components must coexist:

- Source of contamination (mass, bioavailability and concentrations relevant to cause risks)
- Transport/exposure route (from source to receptor)
- Receptor/recipient (with adequate doses and exposure time)

In general, if any of these three components are missing, risk cannot be verified. However, sometimes the existence of a significant contamination source without confirmed transport routes or receptors may warrant mitigation measures.

A proper risk assessment is a multidimensional and complex procedure, which often consists of numerous uncertainties and assumptions, thus requiring specific expertise. Therefore, this project has developed a simplified Risk Identification process (RID) to support decision making and range management for heavy weapons shooting and training activities.

The RID approach has similarities to basic concept of risk assessment and it is designed to be a flexible and repeatable process. The RID can have different levels, and it can be built up from a simple, qualitative risk screening into a more sophisticated, quantitative risk assessment. In the RID process the evaluation of site-specific conditions and receptors that affect the risks on the given site are based on a Traffic Light rating, i.e. using color codes (green – yellow – red) for indicating potential risks. From a management point of view, there should be as few Red Light ratings in the RID as possible. If any of the assessed environmental media or receptor is rated Red, it should automatically lead to follow-up actions such as additional investigations, potentially followed by risk assessment and/or ecological survey. After the additional actions have been carried out, a re-evaluation of the situation should follow until the rating can be changed to Yellow or Green. A Yellow rating in RID indicates either a need for additional data or underlines the fact that the possibility of ecological or health risks cannot be entirely ruled out. If the conclusive evaluation indicates Yellow for any of the environmental compartments or receptors, a monitoring program should be designed to follow-up the corresponding impacts of heavy weapon training on site. A Green rating means that the receptor does not exist at the site or the environmental characteristics are such that neither significant emissions nor contaminant transport are likely to occur.

For each weapon system the sites are delineated according to the areal extent of the possible emissions of contaminants. These sites can serve as designated study areas for environmental investigations. For example in mortar shooting, both firing point and impact area need to be evaluated as indi-

vidual sites. After defining the site, identification of the contaminants of concern and the chemical load, the transport potential is identified based on the site-specific conditions (types of soils, depth to groundwater, distance to surface water, surface water flow paths, vegetation etc.). In the RID, all environmental compartments (surface soil, surface water, groundwater) can be the potential recipient of the emission.

Once risks have been identified, practical recommendations for range management are given. The most common management recommendations resulting from the RID are additional soil and water investigations and adjustments in the monitoring program. Risks can sometimes be avoided or minimized by modifying the training site with environmental protective structures or by moving the training to a less risky location. In the case of acute risk or detected contaminant transport to groundwater, the only management option may be the remediation of the site.

Different management controls include siting and range planning, fixed target areas and firing points, erosion control, rotation of ranges (rest periods), record keeping and propellant burn pans. In addition there exists some engineering controls such as washing stations for vehicles, berms and sand traps and various water management and treatment options.

The most common way to handle soil contamination is by the simple method of excavation. Excavation is often a simple, reliable and fast solution, but there are several issues that might cause excavation to be a problematic choice. Sometimes there are less intrusive methods: if the contamination consists of energetics deposited on the surface (typically back blast area on antitank ranges) then an infra-red (IR) heater is a practical solution for remediation or a high-power magnet can be used for cleaning the top soil of metallic debris. The solubility of contaminants can be reduced by adjusting the soil conditions (pH, organic matter contents, or particle size distribution) by amendments.

The environmental cost-benefit assessment is an important part of choosing the correct method for environmental impact management. The basic principle is that the environmental benefits should be sufficient and more significant than the costs. The benefits can be considered sufficient when the acceptable risk level is achieved. On the other hand, environmental protection should strive to mitigate and prevent environmentally harmful impacts beyond the minimum acceptable level. Therefore the significance of additional benefit relative to cost should be assessed for measures that exceed the minimum level and are possible to achieve with reasonable extra investments. Before choosing an environmental protection approach, it is also vital to take into account all the environmental aspects as a whole. The three subtopics have been described in the previous chapters and they need to be thoroughly cross-examined before choosing risk management or mitigation methods.

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## ACRONYMS AND ABBREVIATIONS

AAMS	Air-To-Air Missile System
ALCM	Air Launched Cruise Missile
AMRAAM	Advanced Medium-Range Air-to-Air Missile
AP	Ammonium Perchlorate
APDS	Armor Piercing Discarding Sabot
ATACMS	Army Tactical Missile System
BAT	Best Available Techniques
BGL	Bekendtgørelse om godkendelse af listevirksomhed, a statutory decree of environmental approval of activities, Denmark
BEK	Støjbekendtgørelsen, Denmark's Noise Order
BIP	Blow In Place
BP	Burn Point (for excess propellant)
C4	Composition C4: plastic explosive, RDX (91%)
CoC	Contaminant(s) of Concern
Comp-B	Composition B: mixture of RDX and TNT (60%/40%)
Demo	Demolition (Range)
DNAN	Dinitroanisole (1-Methoxy-2,4-dinitrobenzene)
DNT	Dinitrotoluene (1-methyl-2,4-dinitro benzene)
DR	Deposition Rate
Dud	Unexploded round (on impact range)
EM	Energetic Material
EOD	Explosive Ordnance Disposal
EU	European Union
FORURL	Lov om vern mot forurensninger og om avfall, Norway's Environmental Protection Act
FP	Firing Point
GCM	Generic Conceptual Model

HARM	High-Speed Anti-Radiation Missile
HC	Hexachloroethane, main ingredient of HC smokes
HE	High Explosives
HEAT-TPT	High Explosive Anti-Tank - Target Practice with Tracer
HMX	Octogen (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)
IA	Impact Assessment
ICRMP	Integrated Cultural Resource Management Plans
IE-Directive	Industrial Emission Directive
IFV	Infantry fighting vehicle
IHE	Insensitive High Explosives
IM	Insensitive Munitions
IMX	Insensitive Muniton Explosives
INRMP	Integrated Natural Resource Management Plans
IR	Infra-Red (heater)
LiP	Lignin Peroxidase
MB	Miljöbalk, Sweden's Environmental code
MBL	Lov om miljøbeskyttelse, Denmark's Environmental Protection Act
MC	Munition Constituents
MLRS	Multi-Launch Rocket System
MnP	Manganese Peroxidase
MoD	Ministry of Defence
MVH	Förordning om miljöfarlig verksamhet och hälsoskydd, a statutory decree of environmental requirements in Sweden
NC	Nitrocellulose
NG	Nitroglycerin (1,2,3-Trinitroxypropane)
NLOS	Non-Line-Of-Sight (indirect-fire ranges)
NQ	Nitroguanidine

NTO	Nitrotriazolone (3-Nitro-1,2,4-triazol-5-one)
OB/OD	Open Burn / Open Detonation (Disposal) range
Octol	High explosive mixture of HMX and TNT (70%/30%)
PAX	Picatinny Arsenal Explosive
PBX	Polymer-Bonded Explosive
PETN	PENTA, Penthrite, Pentaerythritol tetranitrate
PIMS	Phosphate-induced Metal Stabilization
POC	Point of Contact
RDX	Hexogen (Hexahydro-1,3,5-trinitro-1,3,5-triazine)
RID	Risk Identification Process
RIGHTTRAC	Revolutionary Insensitive, Green and Healthier Training Technology with Reduced Adverse Contamination
RP	Red Phosphorus, smoke ingredient (an obscurant)
RVA	Risk and Vulnerability Analysis
SEL	Sound Exposure Level
TNT	Trinitrotoluene (2-Methyl-1,3,5-trinitrobenzene)
UV	Ultraviolet (irradiation)
UXO/UXB	Unexploded Ordnance/ Unexploded Bomb
WP	White Phosphorus (a pyrophoric obscurant)
YSL	Ympäristönsuojelulaki, Finland's Environmental Protection Act

# **PART I GENERAL**

## 1 INTRODUCTION

### 1.1 Background

Recent changes in the European security environment have proved that there is still a demand for strong defence. Defence capability is, among other requirements, based on well-educated personnel that have the know-how to operate high-technology weaponry. Virtual training and other supplementary techniques can be part of military education, but excellent soldier skills can only be achieved through action in theatre-mimicking realistic outdoor conditions with live ammunition. In order to safely operate with heavy weapons, high-quality training facilities are essential.

Armed forces are also expected to fully meet the requirements of environmental protection. Due to the tightening legislative requirements combined with an enhanced understanding of the environmental impacts of military training,

from country to country and environmental assessments, permits and other administrative approval processes have typically been based solely on a national perspective. To better facilitate future international cooperation, environmental protection schemes should be more standardized and take into account specific needs that visiting troops or those training together in multinational coalitions may have. Common guidance and more uniform administrative processes would be beneficial.

### 1.2 Study objectives

The purpose of this project was to collect and assess good practices and technical solutions for environmental risk management at heavy weapons ranges. This guidance document is intended to be a tool for environmental authorities, environmental experts and consultants both inside and outside the defence forces, to help establish adequate environmental protection measures on a case-by-case basis. Another target group is personnel in charge of training and



there is an increased need for more standardized technical solutions and management practices on shooting and training areas. This need is widely acknowledged among various nations. On the other hand, there may be a gap between military needs and the best environmental solutions; in such cases, a balance between the two interests is necessary and it can be achieved through active co-work between authorities.

Both shooting and training activities with heavy weapons and their environmental impacts are unique to the military and they require specific information and guidance which has, so far, been scattered in numerous documents. It is also important to achieve a common understanding of feasible environmental solutions between the military actors, environmental authorities and other stakeholders.

Defence forces increasingly train at ranges in countries other than their own. Environmental requirements vary

shooting activities. This document can help increase their general awareness of environmental impacts and sound training practices in order to mitigate the harmful effects of this training. The report will also work as a tool for outreach with other stakeholders.

The project focused on the full range of environmental aspects of heavy weapons training. The project covered noise management, nature and cultural heritage management and contaminant management. The content of this document focuses on these three topical areas:

- 1) environmental impacts caused by heavy weapons training,
- 2) practices and technologies which could be used to might mitigate some of these impacts,
- 3) recommendations for the impact management and the topics for further study and development.

In this report, the areas of concern are referred to as “heavy weapon ranges” especially when talking about heavy weapon shootings or explosions. When a broader scope of military training is discussed, the area of concern is called “shooting and training area”. Heavy weapon ranges can either have or not have fixed constructions. However, fixed small arms shooting ranges are not included in this report.

This report uses the NATO definition for heavy weapon (20 mm and up in diameter). However this report takes into consideration a wide spectrum of shooting and training activities. Typical weapon systems in use are listed in Appendix 1B.

While the primary focus of this project has been on heavy weapons shooting, explosives and pyrotechnics on land areas, small arms shootings in terrain and heavy vehicle maneuvering that takes place on shooting and training areas were taken into account as well. On the shooting and

contains a summary of the current state of environmental legislation and regulation in the Nordic countries.

### 1.3 The use of shooting and training areas

The main purpose of shooting and training areas is to ensure the operational capabilities of a nation’s defence forces and effective cooperation with allied forces. They are essential for everything from training an individual soldier from any branch of the military to testing complex battle plans. The military must execute operations in all sorts of environments and under diverse scenarios. Consequently, shooting and training areas must provide as realistic conditions as possible with respect to topography, season, day/night, etc.

The use of shooting and training areas include a wide variety of training activities. In addition to shooting with heavy weapons (such as anti-tanks and artillery) there can be small arms shooting, explosives training and pyrotechnics.



training areas there can also be fuel distribution, vehicle maintenance, camping areas, fire-fighting training, landfills, water training areas, runways and helicopter fields but these activities were not included in this work. It should also be noted that only active or new shooting and training areas were considered. Thus, the remediation of contaminated soil after a site has been deactivated was not included.

Because physical solutions are limited and often not feasible, another important area of interest is the management and development of training practices, which address the important goals of military training but minimize their environmental impact.

To help understand the environmental impacts, the document provides some background information about heavy weapons training, contaminants, noise emissions and other possible disturbance on the environment. This report also

There are distinct firing points and target areas. Training also includes manoeuvring with all types of vehicles (tanks, humvees, aircraft, etc.).

Some shooting and training areas are designed for specific branches of the armed forces, while others facilitate joint training operations across branches and among allied forces. Shooting and training areas also vary in surface area. Large areas enable the use of weapon systems that require long distances such as artillery. Also on big ranges there is more flexibility in the shooting locations and in the variety of weapon systems than on the small ones. Shooting and training areas can have very different physical properties and environmental aspects due to their location.

Military requirements form the basis for the types of activities and capabilities needed in various parts of each shooting and training area. On the other hand, environmental aspects can create restrictions on the military use. In



## TYPES OF RANGES

There are many different types of training ranges on a military base. The two basic types of live-fire ranges can be categorized as qualifying and maneuver ranges. Qualifying ranges have fixed firing positions and targets. Maneuver ranges enable the trainees to train “in motion”. Firing points are not fixed, although targets may be. Within these two classes of ranges are direct-fire and indirect-fire ranges. Direct-fire ranges, also known as line-of-site ranges have targets within site of the gunner. The targets are generally fixed, but more modern ranges now have limited-range moving targets. In either case, fire is concentrated on a limited number of targets in a limited area. Examples of these ranges are tank and anti-tank ranges. Indirect-fire ranges also known as non-line-of-site (NLOS) ranges, typically have many targets spread out over a large area, so that the detonation effects are spread across the impact area.

Examples of these ranges are howitzer, rocket, and most mortar ranges. Ranges may be multi-use (using many types of weapons) or single-use.

Other types of ranges include demolition ranges and disposal ranges. Demolition ranges are used by combat engineers and explosive ordnance disposal (EOD) specialists to train with live munitions.

The military also needs disposal ranges to dispose of ordnance that is outdated, damaged, or defective. Open detonation and open burning (OD/OB) of munitions, including large caliber ones, may occur on these ranges. Munition clearance may occur on impact areas when unexploded ordnance (UXO or UXB) is deemed unsafe to move.

some countries the public has access to shooting and training areas. This use includes professionals (e.g., police) and non-professionals (e.g., shooting clubs, hunters). Civilian use of ranges can vary, depending on the location of the facilities and their military use.

The military generally trains during the day and normal workweek. While the military actively tries to avoid

conducting activities during night time, weekends and public holidays, this is not always possible. Night time training has two goals: to practice combat endurance (of individuals or units) and to provide participants with the necessary knowledge and skills for fighting in the dark.

The characteristics and challenges of the shooting and training vary between and within nations. The training

activities may take place on an important groundwater area, which would highlight the need for contaminant management. There might be sensitive habitats or otherwise significant nature values which require attention. The area might be located in a densely populated area, which commonly causes challenges regarding noise. All of these issues need to be considered on all areas but their weight of importance may differ. They also might have secondary impacts on one another, for example contamination of the soil can affect sensitive organisms. Also the possible management methods can have unwanted consequences if all the aspects are not considered carefully. Hence the assessment of environmental impacts of heavy weapon shooting and explosions and the planning of impact management must always be done site-specifically.

## 2 CURRENT LEGISLATION AND GUIDANCE

### 2.1 EU legislation

#### 2.1.1 General

The European Community has harmonized the environmental legal principles across the union but most of the detailed legislation concerning shooting and training activities is country specific. The most important exception is nature protection where EU legislation plays a very significant role. It is to be noted that Norway is not a member of EU but has implemented the majority of Community law in its national legislation.

#### 2.1.2 Noise

The Community noise norms do not regulate shooting and training activities of the military. However, there is a com-

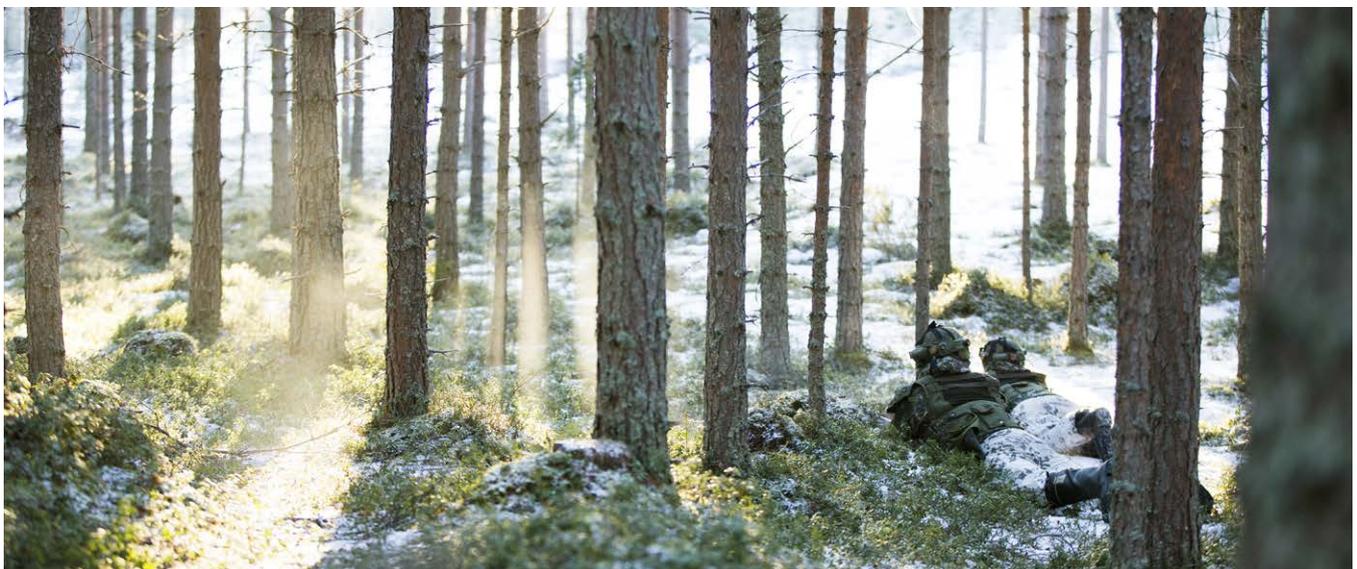
mon approach for the European Community to avoid, prevent or reduce the harmful effects caused by exposure to environmental noise, cf. EU 2002/49/EC relating to the assessment and management of environmental noise. Environmental noise is also regulated at EU level at the source of the noise, with legislation on issues such as harmonized noise limits for motor vehicles, outdoor equipment and other noise-generating products. However, these directives do not apply to noise caused by military activities on military areas.

#### 2.1.3 Nature

The Nordic countries, apart from Norway, are protected by Natura 2000. Natura 2000 includes a coherent European ecological network of special conservation areas designated by the Birds and the Habitats Directives. Norway has adopted national legislation that, to a large extent, corresponds to Natura 2000 directives.

A designated locality is generally protected against interference by the Habitats Directive Article 6 (2), which requires Member States to take appropriate measures to avoid deterioration of natural habitats and the habitats of species in special areas of conservation, to the extent impairment has significant implications in relation to the objectives of this directive. In addition, the special safeguard mechanism calls for impact assessment of plans and projects in Article 6 (3). If a plan or project has a significant effect thereon, the plan or project shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives.

Protection provided for in Article 6 (3) (on plans and projects) can be set aside anyway, if there are imperative reasons of overriding public interest, including those of a



social or economic nature. If the project will damage priority species and/or habitats, a prior opinion from the EU Commission should be obtained.

Military interests can be considered to be capable of constituting imperative reasons of overriding public interest, but this is not explicitly stated in the Natura 2000 directives. The European Court of Justice has not ruled whether the interests of the defence are considered to involve human health and public security.

### 2.1.4 Soil and water

The Groundwater Directive 2006/118/EC pertains to the protection of groundwater against contamination and deterioration. The aim of the directive is to prevent and combat contamination in groundwater within the EU Member States, and it includes procedures for assessing the chemical status of groundwater and measures to reduce levels of contaminants.

There is no exemption for military activities.

There is no EU legislation on soil contamination.

## 2.2 National legislation on pollution

### 2.2.1 Environmental legal framework

The general principles of environmental protection law are very similar in all Nordic countries. Sweden, Denmark and Finland are EU members and the basic principles of EU directives such as the Industrial Emission Directive (IE-directive) are mandatory in these nations to implement. Technically the IE-directive applies only to larger industrial activities, but all Nordic countries implement the basic principles and the environmental permit system also to smaller installations. Norway is, as mentioned, not an EU member but has basically implemented the majority of EU directives in its national legislation. Environmental protection principles include:

- the prevention or reduction of harmful impacts (principle of preventing and minimizing harmful impacts),
- the use of the best available technique (BAT principle),
- the use of best practices to prevent pollution (principle of environmentally best use),
- parties engaged in activities that pose a risk of pollution have a duty to prevent or minimize harmful impacts.

All Nordic countries have a more or less integrated system for environmental permits, which means the environment is considered as a whole in the process. There are differences in the scope of integration between the Nordic nations, but this has a rather limited impact on shooting and training activities of the defence.

In Sweden the majority of Environmental Protection Act is codified into Environmental Code (1998:808, Miljöbalk, MB) which came to force in 1999. It includes among other matters paragraphs concerning environmental permitting. A separate land-use planning act exists as well.

In Denmark, the Environmental Protection Act (Lov om miljøbeskyttelse 879/2010, MBL) is not as consolidated as the Swedish act and resembles more the solutions existing in Norway and Finland. Environmental permits are required based on MBL 33 § and a list of activities.

Norway's Environmental Protection Act (Lov om vern mot forurensninger og om avfall 1981-03-13, FORURL) has principles similar to Danish and Finnish legislation. Action that may cause harm to the environment needs a permit (§11).

In Finland, the stipulations on environmental protection are combined in the Environmental Protection Act (Ympäristönsuojelulaki, 527/2014). It is a general act on the prevention of pollution, which is applied to all activities that cause or may cause environmental damage. In addition to YSL, several other pieces of legislation may be of importance. One of the most important is the Land Use and Building Act.

### 2.2.2 Legal definition of shooting and training area in Nordic countries

In Denmark, types of training areas are specified in the Regulation on noise management of military training areas (Noise Order, Støjbekendtgørelsen, BEK nr 1732/2015), section 3: Military training areas including external outposts that are used to shoot into the actual training area are specified in an annex. Shooting range means fixed ranges that have limited access through berms or structures.

In Finland, a shooting and training area is defined in the statutory decree on heavy weapons and explosions noise levels (903/2017). A shooting and training area is an area used by the military, the border guard or defence industry for heavy weapons shootings or explosions. Defence forces have also training areas where no live round shooting takes place and fixed small calibre shooting ranges.

In Norway, a legal definition for a shooting and training area does not exist. A shooting range for light weapons is defined as a facility for shooting, from fixed firing positions, and in well-defined shooting directions.

In Sweden, a legal definition also does not seem to exist and even administrative definitions seem to vary. Training areas are divided into three categories: 1) shooting and training areas, 2) training areas and 3) shooting ranges. The distinction between the first two is whether heavy weapons are used or not.

### 2.2.3 Legal exemptions for defence purposes

In general it is common in all Nordic countries that the armed forces are expected to follow environmental law to the extent it is possible without compromising the tasks of the defence. Defence activities are unique in the sense that defending the nation's independence is typically laid down in each country's constitution. Therefore it is possible that in some cases there is a normative conflict between environmental protection law and the legal requirement to establish and maintain a credible capability to defend a nation militarily. This normative conflict has, in most cases, been at least partly addressed through defence exemptions.

Swedish Environmental Code's chapter 1 section 5 states that "The Government may, to the extent necessary in order to strengthen defence preparedness in special circumstances, issue rules for the total defence by way of derogation from this Code; this shall not apply, however, to areas in which provisions must be enacted by law." This allows the government to exempt defence issues from the code's regulation as far as this is in line with the Swedish Constitution. The exemption's overarching scope and its generality seems to underline the significance of defence needs in relation to the goals of environmental law itself. Chapter 3 of the Environmental Code defines so-called areas of national interest. This chapter includes a couple of important special regulations concerning defence: Areas that are of national interest because they are needed for total defence installations shall be protected against measures that may be prejudicial to the establishment or use of such sites (chapter 3 section 9 part 2). This paragraph is significant because it allows the Defence Administration to restrict i.e. building within the noise zones of shooting areas. In section 10 it is further stated that "...If the area, or part of the area, is needed for a total defence installation, priority shall be given to the defence interest."

In Denmark, the interests of the Armed Forces may allow for exemptions from environmental legislation, but there is no explicitly stated exemption for the defence.

In Norway, FORURL §8.2 states that actions of defence forces are allowed to the extent they are not specifically restricted by statutory decision meant in section 9, notwithstanding permanent defence installations that do not primarily serve actions of war and have to fully conform with the law.

The Finnish YSL does not apply to activities of the Defence Forces or Border Control where the application of the law could endanger the security of the state or the national security of supply. Basic principles of environmental law must still be followed. This exemption is designed to be used solely in cases where there is no way to follow the normal requirements, especially in a situation where the general security situation would be compromised. If a heavy weapons range would be deemed to require an environmental permit, it is possible to deviate from regular permitting requirements as far as that is necessary to secure the national interests of defence. In such cases, permit provisions must make sure that serious contamination of the environment will not be caused.

### 2.2.4 Environmental permitting and other important legal measures

The Nordic countries have made different choices on how they apply environmental permitting on the shooting and training activities of the military. In Sweden, the customary approach is to require an environmental permit for large-scale shooting and training activities. In Finland and Norway, permits can be required on a case-by-case basis. In Denmark, an environmental permit is not required but environmental noise is handled by detailed tailored provisions on each shooting area.

In Norway, according to the Pollution Control Act all new shooting ranges and those which plan to undergo significant changes need a permit. In addition, the Department of defence has decided to ask for permission for additional shooting ranges in order to get predictability especially to avoid future noise restrictions. The authority is the environmental protection authority of the state (Miljødirektoratet) or regional governor (Fylkesmannen). Norwegian defence has about 50 shooting areas, of which only 5 hold a permit by 2018, but several new permissions are prepared for. The permits issued include noise limit values and restrictions of use on public holidays, allowed weather conditions, monitoring etc.

In Finland, shooting and training areas do not require an environmental permit at listed installations. However, an environmental permit can be mandatory if the use of the training area may cause emissions that could exceed the threshold of acceptable harm. Regional state environmental enforcement authority (Elinkeino-, liikenne- ja ympäristö-

keskus) makes the decisions that a permit is required (or not). Permits are issued by state regional authority (aluehallintovirasto). Several cases have been assessed by court of law and the Highest Administrative Court has decided in single cases both to require a permit and not to require it. In most assessed cases the permit has been deemed necessary. The volume of use has been one of the major decisive factors in assessing the necessity to apply for an environmental permit.

In Sweden, shooting and training areas require an environmental permit. MB chapter 9 deals with actions potentially harmful to the environment. A statutory decree (Förordning (1998:899) om miljöfarlig verksamhet och hälsoskydd, MVH) includes the environmental requirements in greater detail. Some installations or activities require a permit and smaller activities can function with a notification (see MB chapter 9 section 6 and MVH section 2 for more details). Although the necessity to apply for a permit is, in principle, tied to the definition of environmentally hazardous activity, in practice the installation list in section 5 of the MVH is decisive

even if not conclusive. A shooting area is classified as a B list activity, meaning a permit from the provincial government is required. In Sweden, the environmental impact assessment is included in the Environmental Code and is therefore an integral part of an environmental permit procedure. Impact assessment is required from basically all activities that need an environmental permit, but the extent and scope of the process conforms to the significance of the installation or activity (the IA is to be executed in necessary scope). Permit conditions are transferred to use regulations of the training area (KaRö). Basic principles for these use regulations are set in MoD guidance document 17.3.1967 (Försvarsdepartementets skrivelse).

In Denmark, a permit is required for set up or significant alteration of an activity. The list of activities is laid down in a statutory decree (Bekendtgørelse om godkendelse af listevirksomhed, 1317/2018, BGL). Outdoor shooting ranges require environmental permit by BGL annex, section J 203. Shooting ranges are part of streamlined regulation where permits are partly based on statutory decrees (annex 5 part

## NOISE GUIDANCE VALUES

Noise limits in the Nordic countries vary, both in what kind of indicator is used and in what juridical status the limit has. They all aim to distinguish the noise level, where 10 % of the population would perceive the noise as highly annoying.

### Sweden

The Swedish guideline values for heavy weapons are given only for maximum noise, and overall exposure is not taken into account. The noise level quantity of the guidelines is the C-weighted sound exposure level  $L_{CE}$ . It has two numerical values for different numbers of annual shots  $N_a$

- if  $N_a > 100$   $L_{CE} \leq 95$  dB
- if  $N_a < 100$   $L_{CE} \leq 100$  dB

When determining the number of shots, only those that are  $L_{CE} > 90$  dB are counted.

### Denmark

In Denmark the limit values for noise from heavy weapons and explosions are:

- $L_{CE} \leq 110$  dB (exemption 115 dB for four larger shooting areas).
- $L_{c_{den}} \leq 55$  dB.
- $L_{CE}$  is the C-weighted sound exposure level.

$L_{c_{den}}$  is the C-weighted day-evening-night equivalent sound level for the whole year. This noise indicator is penalized by 5 and 10 dB during evening and night respectively. It does not include impulse correction. No long-term averaging has been defined for the day-evening-night equivalent level.

### Finland

In Finland, there is a government decree for noise from heavy weapons and explosions. Two values are given; a guideline value for land use planning and an action value for noise from training activities.

- $L_{R_{den}} = 55$  dB to be used in land use planning for specified land use zones (residential and holiday areas, medical and academic establishments, recreational areas)
- $L_{CE} = 105$  dB (7-19) as an action value for specified land use zones (same as above). If this value is exceeded, noise management is required.
- $L_{R_{den}}$  is defined here as yearly A-weighted day-evening-night rating level added with 5 dB correction for weekends and 15 dB impulse correction.

$L_{CE}$  action value is meant to be used for daytime (7-19) heavy weapon shooting and explosions. During evening, night time, on weekends and national holidays, noise from heavy weapons and explosions should be as low as possible.

### Norway

The guideline values suggested by Norwegian Defence Estates Agency (Forsvarsbygg) is divided into two categories, equivalent noise level from all activities and maximum noise level from night-time activities only.

- The rating level ( $L_{R_{den}}$ ) should not exceed 55-65 dB.
- The maximum level ( $L_{CE}$ ) should not exceed 85-95 dB during night-time. Exception from this noise limit should be limited to a certain number of nights per year.

15). Shooting and training area noise is regulated by a separate piece of legislation that has individual requirements for each of the major training areas.

The Danish Noise Order (Støjbekendtgørelsen, BEK nr 1732/2015) of the Armed Forces' training grounds and firing ranges and training areas noise regulation includes many of the provisions that in other Nordic countries would be included in environmental permits. The order sets the framework for activity level, given as annual number of activity days, list of noise sources used and activity-free periods for each shooting and exercise area.

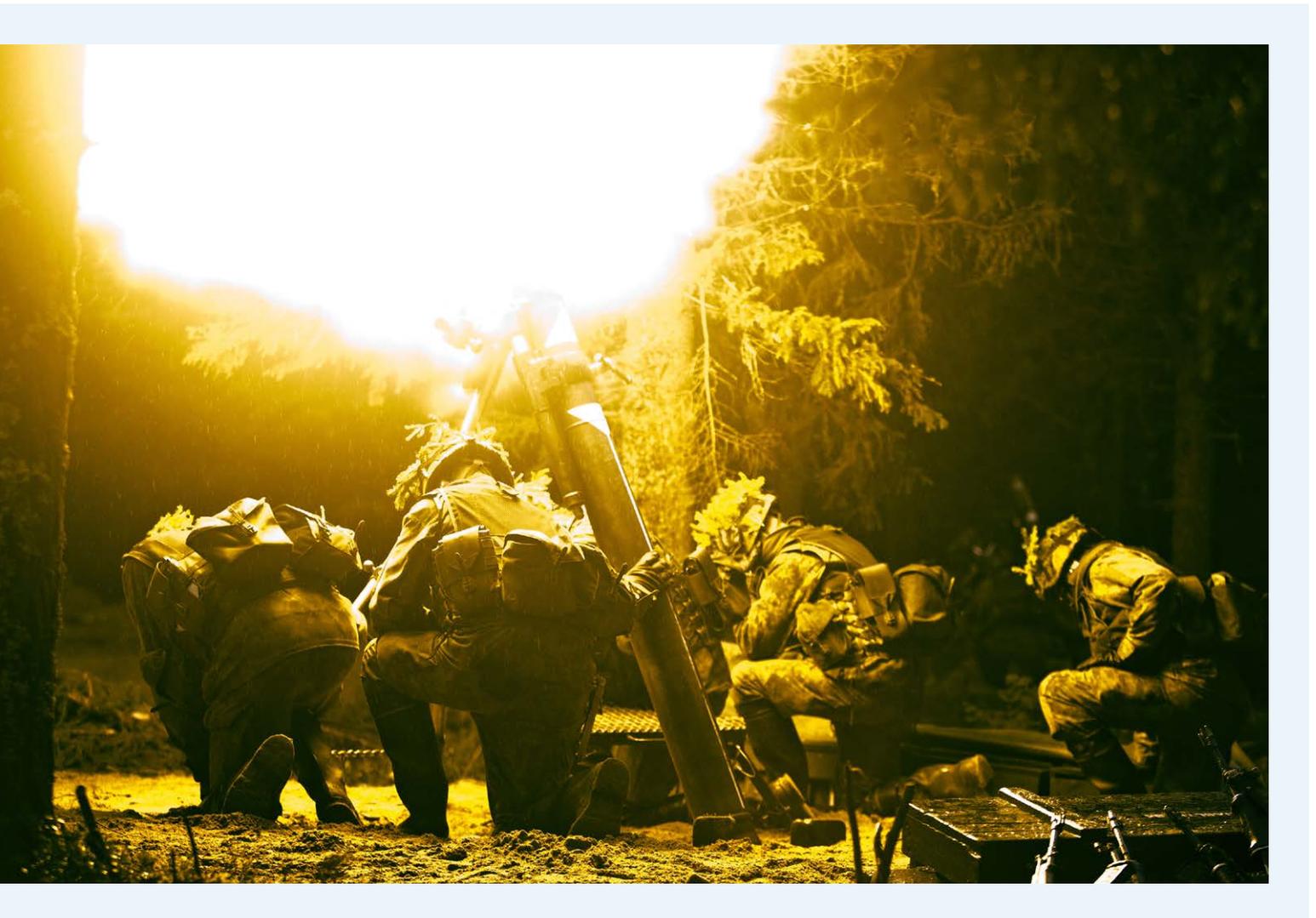
Also the Nature Protection Act (Naturbeskyttelsesloven, NBL, 1122/2018) is essential. Of NBL § 3 follows that there must not be a change in the condition of natural lakes with an area of over 100 m<sup>2</sup>, except for the usual maintenance work streams, cf. (1) and that there must not be made any changes in the condition of moors, marshes, meadows and marshes, water meadows and biological commons, when these habitats individually, collectively or in connection

with the lakes that are referred to in paragraph 1 is more than 2,500 m<sup>2</sup> of contiguous space, cf. (2). Shooting with e.g. grenades may violate the § 3-protection if the grenade lands in a lake; this can disturb the condition of the lake. The municipal council may in exceptional cases make an exemption from the protection of § 3 (1-3).

It seems that in Denmark, nature protection law plays a more significant role in regulating environmental protection of shooting and training areas than in the other Nordic countries. As the aforementioned procedure is ultimately based on EU directives, similar permits are required in other Nordic nations as well but their importance in everyday life is less than in Denmark.

### 2.2.5 Heavy weapons noise

In Finland, there is a new statutory decree on noise levels of heavy weapons and explosions (903/2017). It sets outdoor noise levels for land use planning and heavy weapons shooting activities.



In Denmark, shooting and training areas are regulated by the Noise Order already covered in the previous chapter.

In Sweden, the government has issued guidance values for heavy weapons systems (1998). If guidance values are exceeded, night and evening shootings should be restricted. Guidance values are designed to help the Defence Forces in planning its actions and were developed in cooperation with the Nature Conservation Agency.

In Norway, there are no official noise guidance values for heavy weapons or explosions, but the Norwegian Defence Estates Agency (Forsvarsbygg) has suggested guideline values, and the Norwegian Environmental Agency is positive to the principle.

### 3 IDENTIFICATION AND ASSESSMENT OF ENVIRONMENTAL IMPACTS

#### 3.1 General approach

In order to manage environmental impacts of shooting and training activities on military ranges, one must first

understand the impact mechanisms, emissions and the significance of the impacts specific to a given site. With this information, a decision about the need for further measures can be made. After the initial assessment, further surveys, modelling and more detailed risk assessments may be needed before the correct level of risk management and feasible methods can be chosen. Figure 3.1 shows the general approach of the process suggested in this document.

This chapter will describe the initial identification of possible environmental impacts. Parts II, III and IV will give more detailed information about the environmental impacts and management possibilities concerning soil and water protection, noise and vibration management and protecting nature values.

#### 3.2 General conceptual model

Military training with heavy weapons has several impacts on the environment; these impacts can be either temporary or lasting. During training itself, the use of heavy weapons generates noise. One of the long-term effects of training are the traces of explosives and other contaminants left in the soil and groundwater. Training activities may also

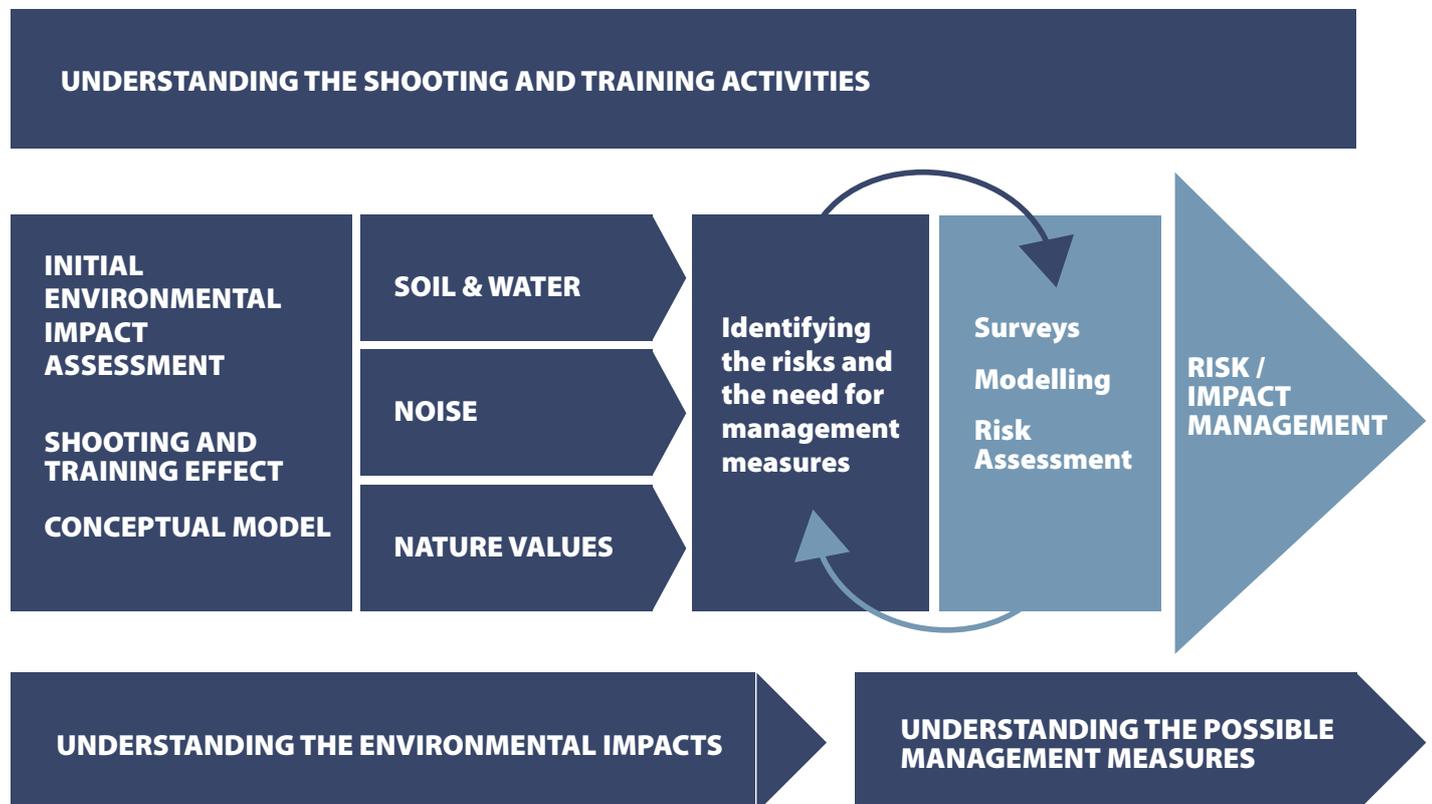


Figure 3.1 The process to identify risks and define the correct level of risk management

negatively affect nature in the area, including flora and fauna. However, it can also be noted that certain species actually benefit from military activities; for example, pioneer species need burnt terrain to thrive.

Metals and energetic compounds are released during shooting events and explosions. Unexploded ordnance (UXOs) and historical dumping sites of excess ammunition form a reserve of contaminants, which can over time contaminate soil, surface water or groundwater. Shooting and explosions also cause noise. Contaminated soil or water as well as noise can further have harmful effects on nature or people. There are also direct physical impacts such as dust, soil condensation and burning.

Heavy weapon ranges are usually vast areas that enclose significant nature values and groundwater resources. The activities and their impacts form a complex web of impacts when all the receptors are considered. An activity can affect one receptor in a negative way whereas another can benefit from it. An additional consideration is that residential areas are getting closer to shooting and training areas, which increases noise exposure and can impact recreational use near the ranges.

It is important to have a conceptual model to help assess the environmental impacts on a certain range. To form a Generic Conceptual Model (GCM) all the activities that may have an effect on the environment are drawn on a map or a generic picture of the area. Figure 3.2 offers an example of a GCM. A real map with possible nature conservation areas and groundwater areas would be even better. With the GCM it is possible to identify the possibly sensitive environmental compartments and to decide the focus area(s) for further assessment.

The next step is to list all the training activities in a simple table and identify the possible primary impacts they may have on the environment. At this point there is no need to assess transport routes or secondary impacts on humans and environment. The primary impacts are noise, dust and air emissions, contaminants, disturbance on soil and direct impact on flora and fauna. An example of identification is shown in Table 3.1.

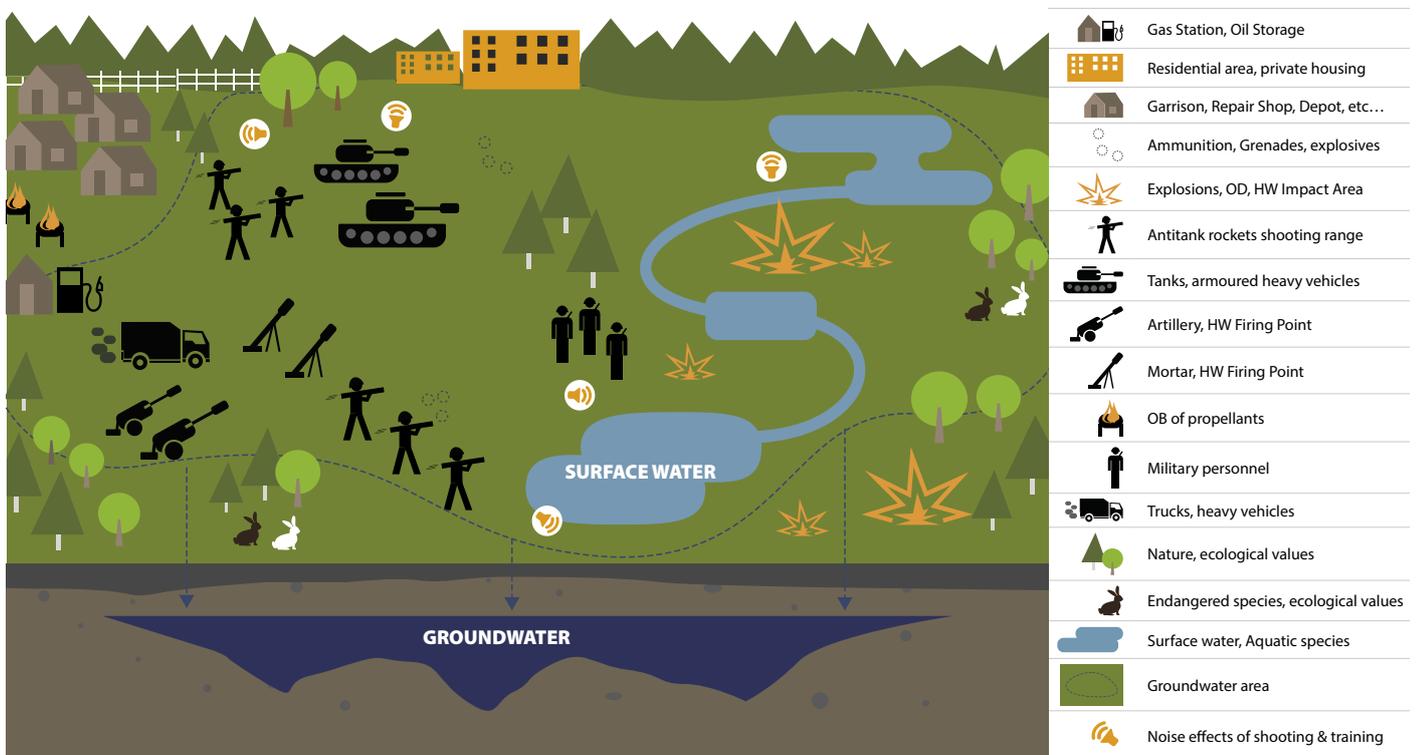


Figure 3.2. Visual presentation of Generic Conceptual Model

**Table 3.1. An example of identification of potential environmental impacts in a shooting and training area.**

<b>SITE</b>	Noise	Dust / Air emission	Contaminants	Soil Disturbance	Direct impacts on flora / fauna	Notes
Rifle shooting range	X		X			
Shotgun shooting range	X		X			Not in military use
Hand grenade area	X	X	X	X	X	
Explosion area A	X	X	X	X		
Explosion area B	X	X	X	X		Rarely used
Artillery firing point	X	X	X	X		
Mortar firing point	X	X	X			
Target area A	X	X	X	X	X	
Target area B	X	X	X	X	X	
Anti-tank shooting range	X		X			
Urban combat training range	X					Only blanks
Accommodation / camp area				(X)		Occasional digging
Landfill			X			
Historical dumping site of excess ammunition			X			
Off-road driving practice track	X	X	X	X		
Fuel distribution site			X			

This document focuses specifically on the environmental impacts and risk management of heavy weapons shooting and explosions (including UXOs and historical dumping sites of excess ammunition). Sites such as landfills, fuel distribution sites and off-road driving practice tracks do not differ significantly from non-military sites; literature and management options concerning them are available elsewhere.

Similarly, fixed small-calibre shooting ranges have their own literature and guidance documents. Nevertheless, although these sites and activities are not discussed in this report, it is important to take them into account when composing an overall assessment of environmental impacts of a shooting and training area.

# **PART II**

# **NOISE MANAGEMENT**

## 4 INTRODUCTION



One of the most significant environmental impacts of training on heavy weapons ranges is noise. Noise can cause annoyance and, in the worst case, negative health effects. To the people in the surrounding areas, noise is a common and well-known phenomenon.

The growth of civilian communities close to training and shooting areas, causes more exposure and negative effects on the inhabitants. This may cause restrictions to be imposed on training activities via land use planning and environmental permitting processes.

Noise from heavy weapons is different from other types of environmental noise. It is impulsive by nature and it has different frequency characteristics than, for example, traffic noise. The main shooting activity happens in sessions during working hours on weekdays, but it may also occur at other times of day and on weekends.

### 4.1 Noise definitions

Noise is, by definition, unwanted or harmful sound. The very nature of this definition demonstrates that noise is highly

subjective. What some people find annoying or unpleasant, others may not. At population level, however, the link between noise exposure and outcome (reaction) is given by exposure-response curves which describe the noise effects on a community.

Sound is a perception (hearing) of waves in a medium (e.g. air or water). Humans can hear a wide range of sound waves amplitudes, but compared to the atmospheric pressure itself, the pressure deviation caused by sound waves is very small.

#### **Noise emissions in heavy weapon shooting**

Noise is created in different ways in different phases of the shooting event. Emissions can be divided into the blast, projectile noise and impact (explosion) noise.

#### **Blast**

The blast from the barrel (muzzle blast) is created by the explosive combustion of the charge of a projectile that is fired. The rapidly expanding gases from the explosion causes an acoustic blast to emerge from the barrel. The blast signature can be described as a point source with strong

directivity. The sound level of the muzzle blast is typically strongest in the direction of fire, and decreases as the off-axis angle increases.

### **Projectile noise**

Projectile noise is created when the projectile travels faster than the speed of sound (sonic boom). The projectile noise forms a cone whose vertex is centered on the moving projectile at any time and whose sides are tangent to the muzzle blast front.

The sound radiation direction strongly correlates to the local speed of the projectile relative to the local sound speed. The areas affected by projectile noise are very limited and normally there are no residential areas within the region. Therefore, the projectile noise is often not considered when dealing with environmental noise assessment from training and shooting areas. An exception is Denmark, where this sometimes is a big problem for the residents near by the training area.

### **Impact/explosion noise**

Detonation noise occurs when the projectile has a detonating charge and explodes on impact. The noise signature can be described as an omnidirectional sound source that emits equal amounts of sound in all directions in a spherical pattern.

### **Characterizing sound**

Sound pressure can be treated in several ways. Depending on how this is done, the sound pressure level must be associated with a quantity in order to make sense. Different measurement quantities can be sorted into two main categories, represented by single events and the average sound.

- The sound exposure level ( $L_E$ ) describes how much sound a single event emits. Since different sound sources have different durations, the total sound is normalized to one second. For shooting noise, a single event is a single shot. For traffic, it is an individual pass-by. Further, the sound exposure level is not necessarily the same in all directions from the source. E.g. most light weapons are noisier in the shooting direction than in the backward direction. This description of the source is called the directivity of the source.
- The average of the sound pressure level is called equivalent sound pressure level ( $L_{eq}$ ). When dealing with non-continuous sounds, it is very important to indicate the time period the average covers. Average time can be for example a whole year.

People generally perceive the evening and nighttime noise more disturbing than the noise during day time. Depending on what time of the day noise occurs sound level can be penalized to create a measure that better describes the disturbance caused. The day-evening-night level ( $L_{den}$ ) is often used, where the sound level during evening and night is penalized by 5 and 10 dB respectively. Evening and night times can vary slightly between the Nordic countries (for example evening: Finland 18-22 / Norway 19-23 and night: Finland 22-07 / Norway 23-07.) This indicator is also, per definition, an average over a year.

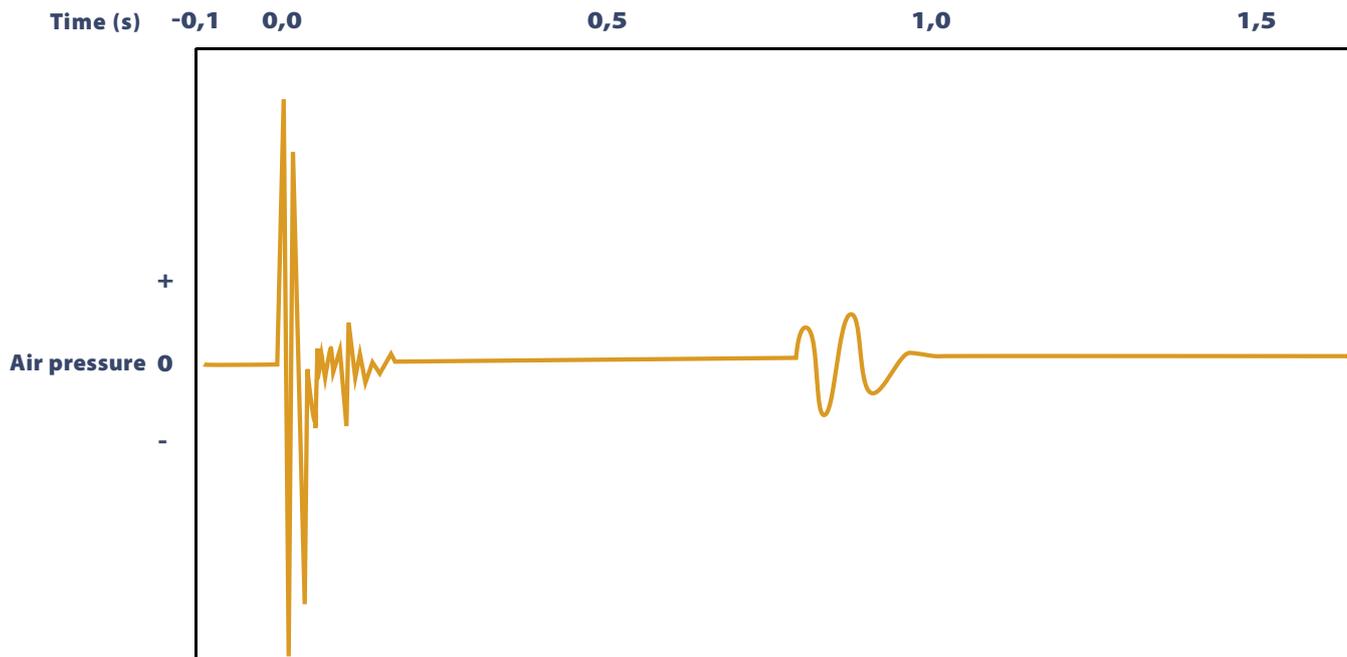
The characteristics of sound are described by its different frequency components (bass and treble). Frequency is measured in hertz (Hz). Sounds of short duration, such as explosions, consist of a wide range of frequencies. Each frequency contributes to the total sound. When a sound is filtered, each frequency is weighted to approximate the sound to the sensitivity of the ear. In this way, we can measure how we would perceive the sound. Especially low frequencies are penalized in both A- and C-weighted noise levels. This is because we do not perceive low frequency sounds as well as we do higher frequencies. The normal human ear can detect sound frequencies from 20 Hz to 20.000 Hz.

Rating level ( $L_{Rden}$ ) is a sound level that is corrected, with a constant or variable, to account for some sound character of the source type. This procedure makes it possible to compare, or merge, sound levels from different types of sound sources. The procedure is presented in ISO 1996-1:2016.

## **4.2 Example of heavy weapon sound**

### **155 mm artillery shot**

The graph in Figure 4.1 shows how the sound from a 155 mm artillery shot looks. The recording is from approximately 2 km in front of the firing position, close to the line of fire. At first, you can see the projectile noise from the supersonic artillery grenade. The grenade forces the air to move to the side, and this creates a ripple in the air pressure. The ripple has a very steep increase and decrease, which reflects in the surrounding terrain, before the air pressure at last stabilizes. After nearly one second, the muzzle blast reaches the microphone. This sound has traveled over two kilometers and has a lower amplitude than the projectile noise at this position.



**Figure 4.1. Recording of a single 155 mm artillery shot. The timeline is centered around the projectile noise, and the muzzle noise reaches the microphone about one second later. The y-axis is air pressure.**

Even though the pressure difference between projectile noise and muzzle noise in this example is large, the noise level is not.

Different sounds are compared with one of the most silent sounds we can hear (a reference value), in a logarithmic manner. This comparison of sound waves to the reference value is called the sound pressure level and is expressed in decibels (dB). Adding a second similar sound source causes an increase of 3 dB in sound pressure level. Therefore if the sound is measured from two sources of 80 dB each, the resulting noise level would be 83 dB. Humans usually perceive a 10 dB increase in noise level as doubling the loudness or sound volume.

When sound recordings are converted into decibels, the level is closely linked to the noise indicator. The graph in Figure 4.2. is an example of this on a resolution of 1 sec-

ond. The peak level (blue line) gives the highest level, but the indicator is not suited for noise calculations. The peak level is usually used only for evaluation of sounds related to hearing loss. However, typically primary concern regarding noise is related to annoyance. The peak level is not a good indicator of how the ear reacts to sound, or how the sound is perceived.

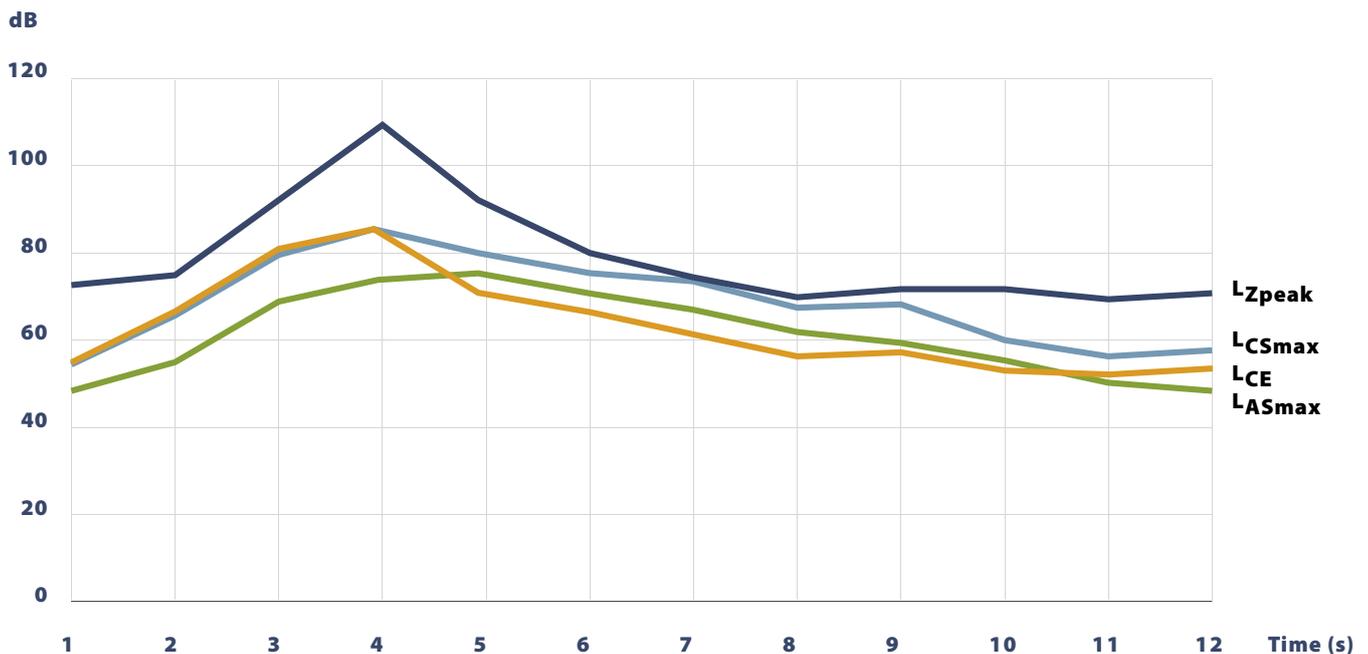
Approximately 25 dB below the peak level we find the  $L_{CE}^1$  and the  $L_{CSmax}^2$ . These indicators show approximately the same noise level as the level increases. As the level drops, the LCE (green line) follows quite well the peak level and it has a far quicker decay than the  $L_{CSmax}$  and the  $L_{ASmax}^3$ .

Due to the A-weighted sound level, the  $L_{ASmax}$  is 10 decibels below the  $L_{CSmax}$ . A-weighting should not be used as an indicator for heavy weapons since it quite effectively reduces the low frequency components of the noise.

<sup>1</sup>  $L_{CE}$  is the Sound Exposure Level (SEL) with 'C' frequency weighting. SEL is the total noise energy in an event expressed as if it had only lasted for a single 1 second duration.

<sup>2</sup>  $L_{CSmax}$  is the maximum sound level with 'C' frequency weighting and Slow Time weighting.

<sup>3</sup>  $L_{ASmax}$  is the maximum sound level with 'A' frequency weighting and Slow Time weighting.



**Figure 4.2. Representation of an artillery shot through four different noise indicators. The peak level, A- and C-weighted level, slow time constant and sound exposure level.**

## 5 IMPACTS OF NOISE

Noise from heavy weapons can have several impacts near training areas. These impacts mainly affect inhabitants and animals in the surrounding areas. The exceptional character of heavy weapons noise makes it more difficult to measure the impacts if compared e.g. to traffic noise. Very few studies have been made about the impacts of heavy weapons noise. Usually the number of inhabitants who live in noise zones of heavy weapons training areas is small. A large number of residents would be needed to produce statistically significant studies based on interviews.

### 5.1 Effects on hearing

Near the heavy weapons firing positions, the noise usually exceeds the general work environment limit value (in Norway) of peak sound level 135 dB; exceeding this level is associated with risk of permanent hearing loss. The shooter and other personnel close to the firing position should wear hearing protection. At the typical distance of residential areas, it is not likely that noise would cause hearing loss. The environmental noise guideline values for heavy weapon noise are well below the limit value for the work environment.

In this report, work safety issues are not described in more detail.

### 5.2 Other health effects and annoyance

Long-term exposure to environmental noise may cause health effects. Cardiovascular disease, psychophysiological effects and sleep disturbances are some examples. Noise also interferes with people's daily activities at school, at work, and at home. Noise may also reduce performance and introduce annoyance responses and changes in social behaviour. The long-term effects from sleep disturbance also have a wide range of secondary health effects, such as increased risk of heart attack, stroke and weight gain among other effects [1].

Heavy weapons shootings do not take place continuously; therefore, effects to health may differ from that of other types of environmental noise. Training takes place mainly at daytime, so sleep disturbance is not a significant factor.

These health effects have been discovered mainly in studies related to road traffic noise, which has been studied for a long time. One of the best indicators of noise annoyance has shown to be the day-evening-night equivalent noise

level  $L_{den}$ . For other noise sources, such as air traffic and rail traffic but also heavy weapons, the level of annoyance is adjusted by a correction value. Studies show that noise from air traffic is 5-8 dB more annoying than road traffic, and rail traffic is 3-6 dB less annoying than road traffic. Small calibre weapons are 12 dB less annoying than road traffic [3].

Regarding heavy weapons, the decibel correction from road traffic annoyance cannot be addressed as a single integer. Instead, there are several different models that range from a combination of noise level and the number of shots per year, to the frequency content from a shot at the receiver. These corrections are complex and the noise calculation program does this conversion. The result is a rated level,  $L_{Rden}$  that is comparable to the annoyance from road traffic.

Similar to the road traffic noise, the noise annoyance from other noise sources is best described by the yearly equivalent noise level,  $L_{den}$ . The activity pattern for heavy weapons, that means how the activity spreads across the time of day, is very different from road traffic as the latter is a more continuous source. More research is needed on noise from heavy weapons in order to better describe how this influences people's health.

### 5.3 Vibrations and rattle

Vibration and rattle are also associated with heavy weapon shootings. Vibrations occur both in the ground and inside a building. Vibrations which travel in the ground (ground borne) dissipate quickly and travel faster than the sound. It is more common that the vibrations come from the sound wave itself (airborne). Therefore reducing vibrations from low frequent sound in the building is best achieved by reducing the noise itself.

Rattle is defined as secondary sound which is born when airborne sound causes vibration in light structures or separate objects (such as windows, dishes, or ornaments), and when these objects then hit their base or support or other objects while moving back and forth. Rattle is usually experienced as very annoying.

In extreme cases the largest explosives or larger propellant charges of the heaviest cannons may excite actual vibration in buildings, for instance in floors or walls. Vibrations from explosions can cause damage to the foundation of a building, but this requires much higher vibration levels than can usually exist in the housing areas surrounding heavy weapons training areas. This kind of damage is more common from construction works, but this is also very rare.

## 6 HEAVY WEAPON NOISE SOURCES

Noise from heavy weapons is usually directional whereas noise from explosions is usually hemispherical. For a gun, the direction of fire is referred to as the "0 degree" point and it also represents the muzzle. The angles increase clockwise around the gun (noise source). It should also be mentioned that the noise level at 90 degrees is the same as at 270 degrees because of the gun's symmetrical construction.

Heavy weapons noise is commonly presented with the whole frequency content instead of one number because it provides a more complete description of the sound.

A detailed list of heavy weapon systems is in Appendix 1B.

### 6.1 Explosions

Generally, explosions generate the same sound in all directions and have two common features:

- Explosions produce hemispherical sound fields if the explosive is buried or detonated at the surface.
- In some combat scenarios, the high explosive round explodes above the target area. When this happens, the sound carries farther and is louder outside the installation boundary. This type of explosion can be particularly annoying at night because the explosive noise can propagate a long distance through nighttime temperature inversions.
- The low frequency components of their acoustic signature can propagate long distances under certain meteorological conditions.

The spectrum of an explosion usually contains more low frequency sound than from the confined explosion of a gun. Humans do not perceive low frequencies, as the sound level is relatively high. Wood frame houses and windows respond to the low frequency component of the sound with rattles and vibration. The low frequency sound waves from explosions propagate over much longer distances than the sound waves of higher frequency. The spectrum of the explosions is related to the size of the explosion so that the larger the explosion, the lower the spectrum.

Lw dB (C)

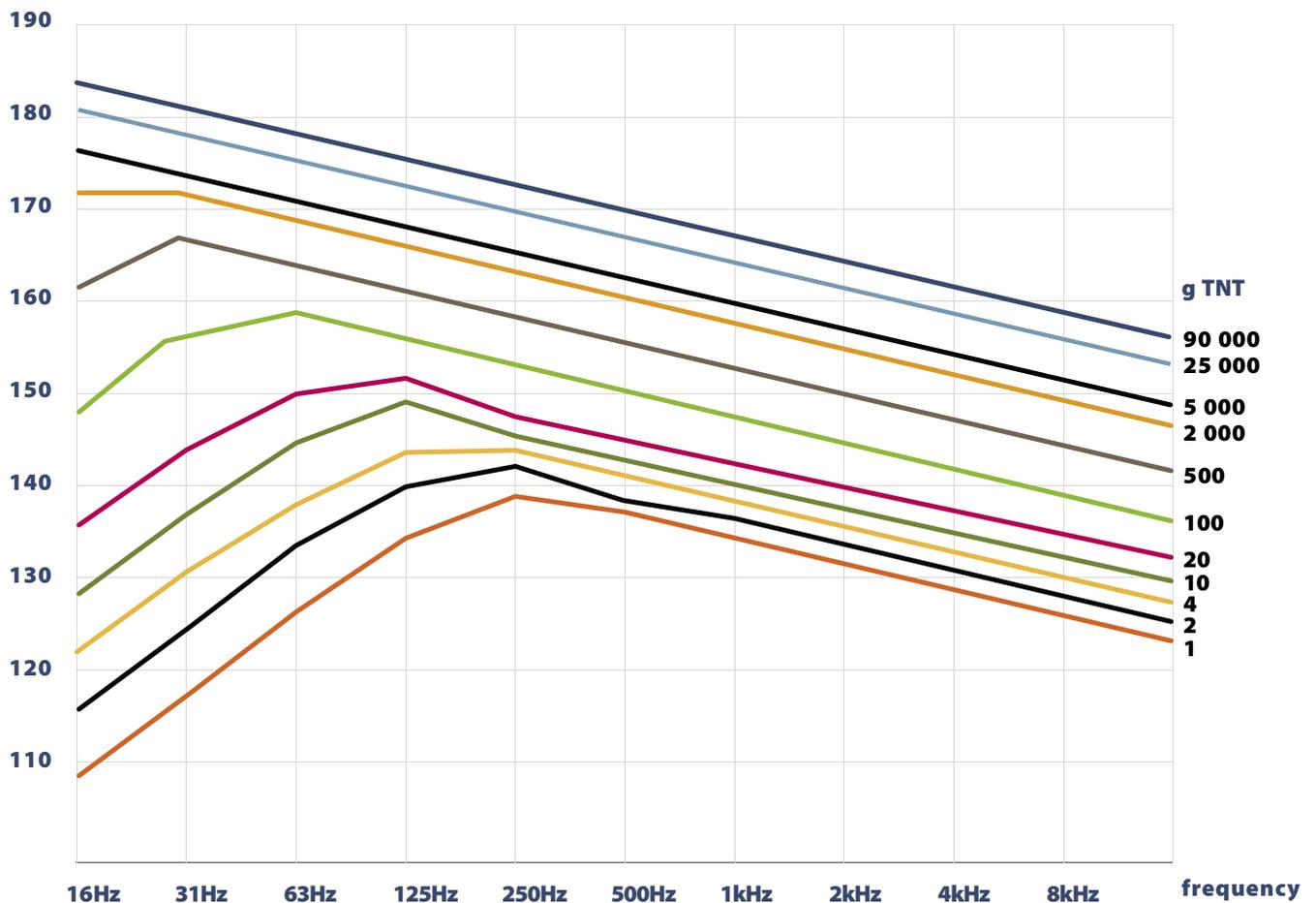


Figure 6.1. Spectrum of the explosions related to the mass of explosive detonated.

The common sources of the explosions are:

- High explosive (HE) rounds for artillery and mortars (e.g., 105 mm and 155 mm howitzer rounds, 60 mm, 81 mm, and 120 mm mortar rounds) when targeted the impact area.
- High explosive (HE) rounds at the target (e.g., 25, 30, 35 and 40 mm Infantry fighting vehicle (IFV) projectiles, 105 and 120 mm tank projectiles, 66 mm, 84 mm and 112 mm anti-tank rockets).
- Minefields.
- Demolition of obsolete ammunition.
- Explosions.
- Hand grenades.
- Live bombs dropped into the impact area, which are the most intense explosive sources.
- Air-to-surface and surface-to-surface missiles when targeting the impact area.

The impact area is defined as the area where the projectile detonates when it hits the ground, whereas the target is typically a thick steel plate, where the projectile detonates when it hits the surface of the plate.

Table 6.1 shows the explosive weight for some of these rounds and bombs.

**Table 6.1. The explosive weight for some heavy weapon rounds and bombs [2].**

Ammunition type	The explosive weight
<b>105 mm HE rounds</b>	M1: 2.3 kg Comp B; 2.177 kg TNT
<b>155 mm HE rounds</b>	M107: 6.985 kg Comp B M795: 10.8 kg TNT or IMX-101
<b>60 mm HE mortar rounds</b>	M720A1: 360 g PAX-21 M888: 360 g Comp B or TNT
<b>81 mm HE mortar rounds</b>	M821, M889: 725 g RDX/TNT M821A1, M889A1: 900 g Comp B
<b>120 mm HE mortar rounds</b>	M933/M934: 2.99 kg Comp B (RDX/TNT)
<b>105 mm tank projectiles</b>	M393A2/A3: 2.994 Comp A-3 M456: 970 g Comp B
<b>120 mm tank projectiles</b>	M830A1: 1.4 kg Comp A3 Type II
<b>Hand grenades</b>	M61: 156 g Comp B M67: 184 g Comp B
<b>Bombs</b>	Mk 81: 45 kg Tritonal or Minol or H6 Mk 82: 89 kg Tritonal or H6 or PBXN-109 Mk 83: 202 kg H6 or PBXN-109 Mk 84: 428 kg Tritonal or H6 or PBXN-109

Many military demolitions are combinations of more than one kind of explosive. Knowing the absolute weight of the explosive gives an incomplete picture of the noise level since explosives differ in their efficiency. To predict the noise level from a particular combination of explosives, each type of explosive must be converted to the equivalent weight in trinitrotoluene (TNT). The efficiency factors for correcting different kinds of military explosive to equivalent weight in TNT can be found in a study by Raspet and Bobak (1988) [4].

## 6.2 Shaped explosions

Shaped explosives are used by combat engineers and are designed to direct explosive energy in a particular direction.

For instance, a 7 kg shaped charge may be configured to direct its explosive energy into the ground to make tank traps. Since the energy is directed to the ground, the charge makes less noise than a 7 kg unconfined explosion, which would make sound that propagates in all directions.

## 6.3 Gun tubes

The propellant blast from gun tube is one of the most common noise sources.

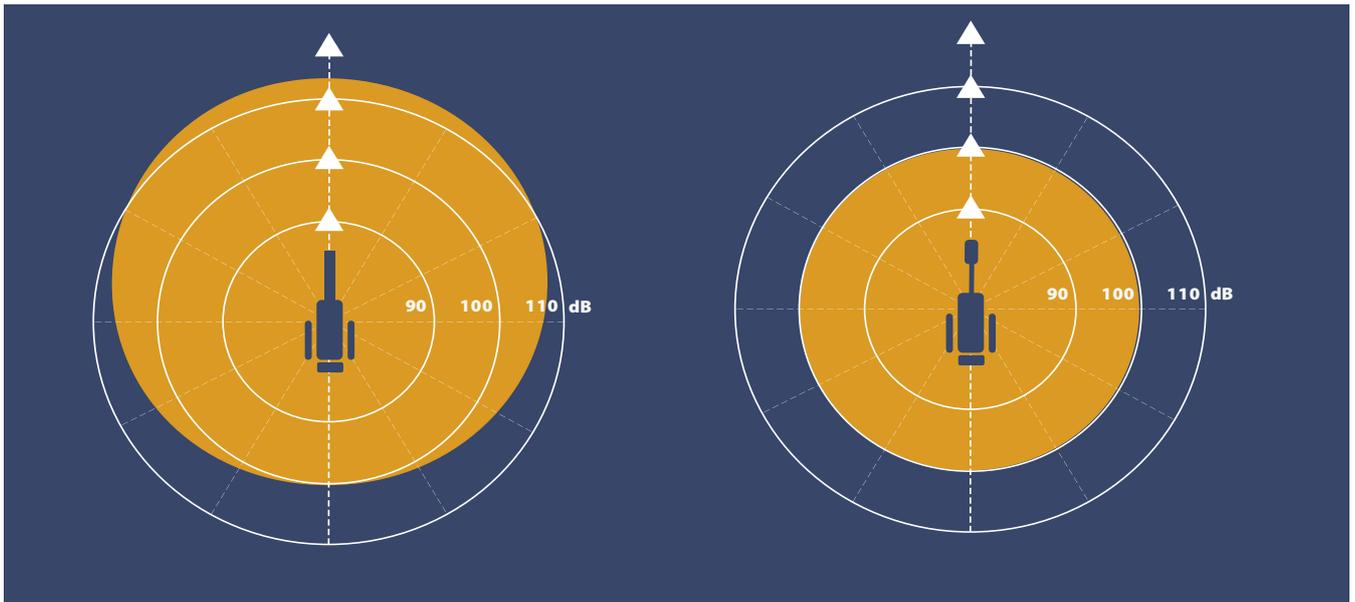
Common gun tubes are:

- Mortars: Muzzle-loaded, smooth-bore, high-angle-of-fire weapon
- Artillery Cannons
- Tank guns
- Cannons (mounted on combat aircrafts and helicopters)
- Cannons (mounted on infantry fighting vehicles)

The smaller the caliber of the gun tube, the higher the dominant frequencies in the acoustic signature are. The longer the gun tube, the lower the amount of acoustic energy released into the air.

When a 120 mm tank gun is fired, a gun tube generates 4-13 dB more noise at 0° (in the direction of fire) than at 180° (directly behind the firing point). At 90° to the direction of fire, the level is 5-9 dB greater than at the same distance directly behind the firing point.

The sound level of a propellant blast behind a firing point depends on the elevation angle of the gun tube. A direct fire weapon, such as the 120 mm tank gun, is nearly horizontal



**Figure 6.2. 155 mm howitzer without muzzle brake (left) and 155 mm howitzer with muzzle brake (right) [5].**

when it fires and the sound level experienced by someone standing on the ground is 4-13 dB higher in front than in back. However, indirect fire weapons, such as a mortar, are fired at an angle; as the angle of elevation increases so does the noise level behind the firing point.

The sound type and level produced by a gun is highly affected by the design of the tube itself.

In order to reduce the weapon's recoil, the muzzle break is introduced to deflect some of the propellant blast to the rear and sides. Gun tubes mounted on heavy platforms like tank gun and naval gunships do not require muzzle brakes, whereas the towed 155 mm howitzer is equipped with a muzzle brake to compensate for its relatively light weight.

The difference in sound directivity between 155 mm howitzers with and without a muzzle brake is shown in Figure 6.2. Note that the sound field from the howitzer with the muzzle brake is more circular.

Shorter guns are louder than longer guns. When a projectile is fired from a longer gun tube, it leaves the tube at a higher velocity than when fired from a shorter tube. This is because the longer tube allows more of the energy from the propellant to be converted into the projectile's kinetic energy before the projectile leaves the tube (and the remaining propellant washes out of the end of the barrel). Since this remaining propellant is responsible for much of the noise that a gun makes, it stands to reason that the more propellant energy that goes into moving the projectile, the less will be left to make noise.

Therefore, if the same weight of propellant is used in a 120 mm mortar and a 105 mm howitzer, the propellant blast (and thus the sound) from the mortar will be higher than from the howitzer.

Gun tubes that are large in both length and diameter are expected to fire a large projectile and propellant charge.

The gun tubes increase in size, the low frequency proportion of the sound of the propellant blast also increases. For example, the spectrum of a 5.56 mm rifle has most of the energy around 500 Hz, while the spectrum of a 120 mm tank cannon has most of its energy around 15 Hz. Because the human ear is much less sensitive to sound at 15 Hz than at 500 Hz, a rifle at a peak level of 115 dB would sound a lot louder than tank cannon at a peak level of 115 dB.

Some rounds fired from long gun tubes (including rounds from the IFV canons, tank guns, and howitzers fired with large charges) are supersonic. As with a sonic boom, these supersonic speeds result in bow shock waves (also known as a ballistic wave). The bow shock wave propagates out from the path of the bullet.

Both the speed of the round, when leaving the gun, and the diameter of the round are important variables to determine the size of the shock wave. The diameter's importance can be illustrated by the difference in shock waves from the 120 mm High Explosive Anti-Tank - Target Practice with Tracer (HEAT-TPT) and Armor Piercing Discarding Sabot (APDS) rounds.

The HEAT-TPT round is 120 mm in diameter and has a fuse protruding from the front. When the fuse strikes armor, a shaped charge explodes forward into vulnerable areas of the opposing tank, whereas the APDS round drops its sides after leaving the gun tube. When the sides fall away, the projectile's kinetic energy is transferred from the beginning 120 mm projectile to a 40 mm tungsten core. Because the remaining projectile is now smaller and faster, it can more easily pierce armor and, at the same time, the new smaller diameter produces a smaller ballistic wave than the HEAT round.

## 6.4 Rockets

### 6.4.1 Anti-tank and anti-fortification weapons

These weapon systems are used in direct fire at ground targets from a ground position. Ground forces employ several rockets against armored targets, such as tanks and infantry fighting vehicles.

The common anti-tanks:

- Portable, single-shot, shoulder-launched, anti-tank rocket weapons.
- Portable, single-shot, shoulder-launched anti-fortification rocket weapon.

When an anti-tank rocket weapon like an 84 mm AT4 is fired, it generates 9-13 dB more noise at 180° (directly behind the firing point) than at 0° (in the direction of fire). At 90° to the direction of fire, the level is 6-7 dB greater than at the same distance directly behind the firing point.

Noise from anti-tank rocket weapons is dominantly emitted to behind the firing point and therefore can cause significant impact if residential areas are located behind the firing points (Figure 6.3).



Figure 6.3. Acoustic directivity of 112 mm Apilas anti tank weapon

### 6.4.2 Rocket artillery

This weapon system is used in indirect fire at ground targets from a ground position. For attacking distance targets, this type of artillery is equipped with rocket launchers instead of conventional guns or mortars. Both the real and training rounds leave the rocket tube at supersonic speeds. For this reason, the ballistic wave must be taken into consideration when assessing the Multi-Launch Rocket System (MLRS).

### 6.5 Missiles

Missiles have two noise impact areas, the firing point and the impact point. Both are much like the noise from explosions, but the firing point has a distinct directivity pattern associated with it.

The missiles are divided into following categories:

- Anti-tank missiles (mounted on a tripod or shoulder-launched)

These missiles used in direct fire at a tank or infantry fighting vehicle from a ground position. Examples are Tow and Javelin missiles.

- Surface-to-air missiles (shoulder-launched or vehicle-mounted)

These missiles used in direct fire at an aircraft from a ground position. Examples are Stinger missile.

- Surface-to-surface missiles

This type of missile is designed to be launched from the ground or the sea and strike targets on land or at sea. They are often powered by a rocket engine or sometimes fired by an explosive charge, since the launching platform is typically stationary or moving slowly. Examples are MGM-140 Army Tactical Missile System (ATACMS), cruise missiles, like Tomahawk, ballistic missiles, like Trident II D-5 and anti-ship missiles, like Harpoon. The noise from these missiles is contained near the firing point, except for ones that obtain supersonic speeds where the ballistic wave must be considered. For over water supersonic flight, sonic boom penetration may be an issue regarding to potential effects on marine mammals.

- Air-to-surface missiles

This type of missile is designed to be launched from military aircraft at targets on land or sea. The two most common propulsion systems for air-to-surface missiles are rocket motors, usually with shorter range, and slower, longer-range jet engines. Examples are Maverick, ALCM, HARM, Hellfire, and Penguin. The noise

from these missiles is associated with three phases: Launch, flight, and explosion. The launch and flight noise are normally not an issue since they occur within the boundary of firing ranges but the explosion noise is similar in detail to the open-air explosions.

- Air-to-air missiles

This type of missile is fired from an aircraft in a purpose of destroying another aircraft. AAMs are typically powered by one or more rocket motors, usually solid fueled but sometimes liquid fueled. Examples are Sparrow, Sidewinder, and AMRAAM. The noise from these missiles is normally minimal since they are used within ranges and are launched at high altitudes, which provides a significant buffer to people and wildlife.

## 7 NOISE RISK IDENTIFICATION

In a case of heavy weapons training, the risk caused by environmental noise can be determined from different viewpoints. For a heavy weapons training area operator, the main risk is annoyance due to noise. This may lead to a conflict with surrounding communities and eventually to limitations of training opportunities by e.g. strict environmental permit conditions. These limitations even can compromise the execution of military training objectives and therefore the capabilities of military force.

For surrounding communities, the risk of heavy weapons noise can be seen as limitation in developing residential areas and business opportunities. For neighboring people heavy weapon noise can decrease the perceived quality of living environment.

The role of environmental authorities is usually monitoring and evaluating the risk of noise by comparing available noise information to national limit values and taking into consideration feedback from surrounding communities. The result of this evaluation is usually presented as conditions in environmental permits or equivalent regulations. Regulations can be given in the form of noise guidance or limit values and/or restrictions on operation hours.

In order to reduce the risk of having unwanted restrictions on military training areas, the noise risks of heavy weapons training should proactively be determined.

For identifying the risks of noise produced by heavy weapons training, a detailed knowledge of the training area, noise emissions, training activities, geography and nearby communities is essential. A risk identification process is presented in Figure 7.1.



Figure 7.1. Risk identification and management process

## 8 NOISE MANAGEMENT

Most favorable and effective noise mitigation methods usually used for environmental noise, such as reducing noise emissions, are not applicable to training with heavy weapons. For reducing the effects of noise from heavy weapons training, several noise mitigation or management methods are needed simultaneously. Unpredictable factors like weather, training schedules and objectives and other factors combined can lead to situations where noise can cause a negative impact even when noise mitigation methods are utilized. However, possible measurements are discussed below.

### 8.1 Land use planning

Land use planning is an effective tool in noise management, especially in the long term. If noise areas of heavy weapons training are taken into account in land use planning, it will prevent building of new housing or other noise sensitive facilities close to areas where noise from training activities exist. If noise is not considered, new residential areas or other noise sensitive facilities will slowly spread close to training areas. This development will eventually and gradually restrict heavy weapons training possibilities.

### 8.2 Planning the training operations

#### 8.2.1 Scheduling

Planning of heavy weapons training schedules can be an effective way in reaching noise management objectives. Training should be scheduled so that most noisy activities are performed at daytime on weekdays. Avoiding excess training activities during weekends and nighttime is good practice in noise management.

#### 8.2.2 Taking weather conditions into account

Weather conditions have a major influence on sound propagation. This is especially the case at large distances, which often is applicable at training areas. For example, at sound propagation over a 2 km distance, noise exposure can vary more than 30 dB between up- and downwind.

Therefore, it is possible to reduce noise exposure by ensuring that the activities are completed mainly on days where weather conditions are least favorable for sound propagation. Or activity locations can be adjusted to the actual weather conditions.



**Figure 8.1. The three factors of a balanced view of noise management**

A balanced view of heavy weapons noise management means that all the objectives of different stakeholders are taken into account in a way that everyone's goals are satisfactorily met. In order to succeed in executing a balanced view of noise management, a constant and continuous collaboration between all relevant authorities and military organizations must be established.

Especially at inversion, i.e. increasing temperature at increasing height over terrain, the noise exposure at certain areas can be considerably louder than normal due to focusing of the noise. Activities which involve larger heavy weapons and explosives should therefore be avoided at inversion. Inversion often occurs in the period after sunrise.

While changes in daily weather conditions can usually not be taken into account when planning training, it is possible to plan training taking into consideration typical seasonal weather phenomena. For example in spring and autumn mornings after cold nights, an inversion layer often exists in the morning hours and can cause noise from training to focus in residential areas where noise is not usually very loud. Scheduling noisy activities on midday and afternoon hours during these seasons could be an effective noise management procedure.

### 8.2.3 Increasing distance

Noise exposure can be reduced by increasing the distance to the nearest neighbor. This, however, demands that the training area have a certain size. Since most heavy weapons and explosions are dominated by low frequencies, the air absorption will be minimal. Therefore, the noise exposure will be reduced approximately 6 dB for every distance doubling. E.g. If the distance to nearest neighbor is 500 m, a 12 dB noise reduction can be achieved by increasing the distance to 2 km. On actively used training areas, this option to increase the distance to neighbors is often already fully utilized or very restricted.

## 8.3 Registration System

A registration system is necessary to monitor the use of the ranges and to document to the authorities that the scope for planned activities and activity-free periods are not exceeded. Input to the registration system is used type of ammunition, site and date. This is the same input used to calculate the noise output from different activities. Thereby, registration of the ammunition use will indicate if the activities is the same as predicted in the calculations. It is important to note that the calculations often are on yearly basis.

For example, the registration system in Denmark is able to document compliance with the maximal noise exposure SEL(C) = 110 dB/115 dB, using the distance criteria.

For noisy activities using heavy weapons and explosives, the registration system therefore includes the following information:

- Firing line (area/shooting line/ coordinates).
- Weapon system and ammunition used.
- Weapon height.
- Distribution of the number of shots over the whole day.

## 8.4 Good communication and outreach

The perceived nuisance or annoyance of noise is reduced if the reason and duration of noise incidence is known. The noise produced by a friendly and nice neighbor is less annoying than noise produced by an unknown, distant or even unpleasant neighbor. Attitude towards the noise source plays a key role in perceived noise disturbance. Affecting general public attitude towards military training via different kinds of public relations activities can be a very cost-effective noise mitigation method.

There have been several good experiences of using different methods of communicating with local communities near training areas. Training calendars and information about training events can be announced in local papers, billboards near the ranges and on the internet. A feedback system where people can express their views and can report or even discuss noise disturbance related to training activities can be effective ways to mitigate the noise problem. Information sessions where neighboring communities are invited can be one way of distributing knowledge about training activities. Common questions from neighbors is: "Where is the noise coming from?" "Why is it so loud this time?" or "Why is there noise at this time of day?" If a proper and satisfying answer is given to the person complaining, the annoyance can be diminished. On the other hand, if the person feels unsatisfied with the given information, the noise annoyance can increase.

### 8.4.1 Announcement system

Some of the countries have very good experiences with planning a long-term activity schedule and publishing it once or more a year. The planned activities and days without activities applicable for the next period will give the neighbors and the community a good overview and predictability for what to expect from noise annoyance. This has a very good effect to prevent complaints, and to make less annoyance for the neighbors. The period can for instance vary between 2 and 6 months. The announcement can be put on the internet, which gives neighbors the possibility of getting information about the planned activities in advance and they can thereby plan their own outdoor activities. It is imperative that the plan is updated, and that the activities occur according to the plan. Otherwise irritation might be even higher in the surroundings.

Another solution is to design a flyer describing the activities at the shooting ranges and the purpose of activity-free periods. In addition, the flyer should contain a link to the published activity calendar.

However, using an announcement system should hold flexibility which enables changes in the schedule if needed.

#### 8.4.2 Feedback system

It is very common that neighbors of heavy weapons training areas give feedback concerning noise related to military activities. Such feedback is usually given via phone calls or e-mails. It is useful for the organization maintaining the training area to have a system for receiving and processing this feedback. Feedback should be directed to range control or an equivalent place in the organization. There might be designated personnel to handle complaints but in some sites it has proven to be beneficial to have the operative personnel that are training i.e. making the noise, to talk to the complainers themselves. They know the activities, weather and other conditions and reasons for possible deviations from routines. Personnel handling or responding to inquiries and complaints should be instructed on the appropriate ways of dealing with people with high engagement and who might be highly annoyed. It is important to handle people with the utmost respect, since the operations disturb their homes and leisure time.

All feedback should be recorded and processed so that information obtained can be useful to noise management procedures. Contact information about giving feedback or complaints should be published on the training area's internet page so neighboring communities are aware of these possibilities. This is also important for securing improvement work.

It is good to remember that feedback can be negative (complaints) or positive and the feedback system needs to take both of them into account.

#### 8.5 Noise attenuation using noise screens

Since noise from heavy weapons is dominated by low frequencies, noise attenuation using noise screens has only a minor effect and the screens need to be placed close to the noisy activities or neighbors. Noise screens are therefore not appropriate when the noisy activities are distributed over a larger area, since the distance between noise screen and farthest activities will be too far. Also it is not feasible to place screens around target areas which are quite large. Screens placed close to some noise sources



Figure 8.2. An example of a safety berm at a demolition area that has also noise screening properties.

(for example explosions) can compromise safety or they may get damaged.

At smaller activities with fixed positions, noise screens can be a solution to achieve noise reduction. The effect of a noise screen can be up to 15 dB. Noise screens have been used, for example, to reduce noise from anti-tank weapons firing positions.

Pits or berms are used around explosive training or demolition sites mainly for safety reasons. Berms or pit walls can also have some effect on noise attenuation. These structures can reduce noise with smaller explosions but are usually negligible when the mass of explosive charges are 5-10 kg or larger.

## 8.6 Emerging techniques

### 8.6.1 Noise attenuation using foam

By covering explosives with foam, it is possible to reduce the noise. This method is especially useful with smaller explosions/blast less than 2 kg TNT (or equivalent). A noise reduction up to approximately 10 dB can be achieved if the thickness of the covering layer of foam is approximately 1 m.

At explosions/blast between 2 and 10 kg TNT (or equivalent), the noise reduction is reduced to 3-4 dB.

At explosions/blast more than 10 kg TNT (or equivalent), the noise reduction is expected to be insignificant. However, it is possible that a considerably thicker layer of foam, more than 2 m, will have a damping effect.

To prevent soil contamination, it is important to make sure that the chemical content of the foam does not have harmful environmental effects.

## 9 RECOMMENDATIONS

Noise mitigation methods applicable for heavy weapons training are limited. Some technical solutions for reducing the noise emission of weapons or explosions exist, but they are generally not usable for military training purposes.

- Noise zones should be established and taken into account in the land use planning
- Scheduling noisy activities at daytime on weekdays. Training at weekends, nighttime and unfavorable weather conditions should be avoided.
- Establish a feedback system concerning noise complaints and inquiries related to military activities and noise annoyance.

- Establish system for announcement of planned activities and respite periods to the public. It is important to update the plans and to follow them! Changes in activities must be corrected and communicated upfront, and as early as possible.
- Invite neighbors in the community to events, being acquainted with activities in the shooting field. Good relations make the community more robust handling noise
- Noise from small explosions/blasts can be reduced by covering the charge with foam. Be aware of contamination risks.

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**PART III**  
**NATURE AND CULTURAL**  
**HERITAGE MANAGEMENT**



## 10 INTRODUCTION

Military training may have considerable impacts on the nature values and cultural heritage of the training area. Impacts are often negative, but there may be some positive effects as well. Areas disturbed by fire, heavy vehicles or grenades, for example, provide suitable living conditions for some species.

Military training areas are unique because they have not been affected by the presence of modern commercial forestry, agriculture or urban life. Therefore, a training area often works as a reference landscape that has not been subject to large-scale intense management impacts such as clear felling, soil preparation, the use of fertilizers and chemicals or the extreme effects of a dense city population. That is why species that were common in primeval forest or in an old type of farming landscape can still exist here.

Cultural artifacts may also be present in the terrain. It is important to systematically take them into consideration so that these reminders of our history are properly protected.

The challenge is thus to maintain the unusual conditions of the military training areas and still be able to use these areas for their main purpose. Often, it is possible to gain synergy between military use and nature protection, which

can also provide good publicity for the military with the general public.

This chapter addresses how to maintain the areas, perform military training and live-fire while being aware of nature values, the cultural heritage and be motivated to preserve them. This chapter has a wider perspective of military activities than just heavy weapons shooting to include human presence and heavy vehicle maneuvering.

## 11 GENERAL OVERVIEW OF NATURE ON SHOOTING AND TRAINING AREAS

From nature value point of view military areas are not a homogenous group. Some forested areas are treated as normal commercially used forests whereas the most valuable nature areas are treated like protected areas and often have a formal protection status.

Appendix 3A contains a short introduction to nature on military training areas for each country participating in this project. Table 11.1 provides a general overview of military land areas (not only heavy weapon ranges) for each of these countries. Of particular note is the sizeable amount of military land that falls under Natura 2000 relative to Natura 2000 of all land in each of these countries.

	Military training land area		Natura 2000 protected military areas		Natura 2000 in total
	Hectares	Military land area compared to total land area (%)	Hectares	Natura 2000 on military land area (%)	Natura 2000 Percentage of total land area (%)
<b>Finland</b>	210.000	0,6	30.000	14	14
<b>Norway</b>	560.000	1,5	-	-	-
<b>Denmark</b>	32.000	0,7	16.000	50	8
<b>Sweden</b>	378.000	0,9	162.000	43	12
<b>Germany (US Army)</b>	38.000	NA	33.000	87	15

**Table 11.1. Overview of military lands, by country**

## 12 IMPACTS ON NATURE VALUES

The use of heavy weapons and other military training requires consideration of a number of impacts to nature values. The impacts are site-specific and their importance needs to be evaluated for each area and situation. The main impacts are described in this section.

Impacts can be positive or negative, depending on the type of training and the sensitivity of nature values. In general, long-term heavy weapons training changes habitats at the site, usually creating open habitats because of frequent physical disturbance. Impacts can be direct or indirect. Erosion caused by heavy vehicle maneuvering and target area explosions are examples of direct effects. On the other hand, contamination of soil and water, human presence and noise could have indirect impacts on nature values. In addition, keeping the military areas open for the training reasons exposes the areas to invasive species, which needs to be recognized and controlled.

### 12.1 Noise and human presence

It is well known that noise negatively affects many animals, especially vertebrates like birds and mammals. Less is known about the effects on other groups of animals. The

presence of human activity in military areas can disturb nature; however, studies have shown that many animals can adapt to continuous noise and the presence of humans. This varies widely, not only by species, but also by individuals.

The degree to which noise disturbs vertebrates, especially birds, is difficult to determine. Most researchers agree that noise can affect animal's physiology and behavior. If noise becomes a chronic stress, it can be injurious to animal's energy levels, reproductive success and long-term survival [16]. For example, continuous noise has been found to reduce avian reproductive success with females laying smaller clutches [8].

The direct effects of military activities on avian behavior appear to be species-specific and to depend on the history of military disturbance [11]. Individuals in areas subject to such disturbance over extended time periods did not seem to be affected as much as individuals from areas in which military disturbance was relatively new. Some species may be capable of adapting to military disturbance via habituation or learned tolerance [6].

In Finland, white-tailed eagles, osprey and whooper swans have successfully bred near or within heavy weapons shooting target areas. Larger mammals, such as deer, Eurasian lynx,



Figure 12.1 Sand dunes in Lohtaja Finland

and bear seem to tolerate noise quite well. The most timid animals likely disappear from these areas, while only a small number of animals adapt to the continuous disturbance.

Human presence and military activity in general cause effects similar to the effects of noise, and the variation in animal behavior is quite large. If the activity has been going on for a long time, species most adapted to noise are more numerous than timid ones.

There can also be indirect effects from physical disturbance on animals. Several studies have observed effects [14]:

- vegetative structure, flora composition, and even the capacity for succession can be altered in a number of ways by military training
- avian density, richness, species composition, can be influenced by the above mentioned changes, which further involves site abandonment or new distributions and altered community structure
- high levels of habitat disturbance tend to reduce avian biomass and displace sensitive, secretive species
- habitats severely altered or degraded by training tend to support greater numbers of exotic or disturbance-tolerant plant and bird species
- the seasonal timing of military activity may significantly influence its impact on vegetation and, hence, associated avifauna.

## 12.2 Physical disturbance

Direct physical disturbance by military training (explosions, fire, heavy vehicles maneuvering) and keeping the training areas open (regular cutting and controlled burning) may significantly influence plant and animal communities in military training areas.

Explosions and the use of heavy vehicles, such as tanks, usually produce negative effects, in terms of not only the numbers of each species, but also the number of species found in the area [10, 17]. On the other hand, large numbers of threatened and endangered species and high biodiversity are found on active and former military training areas. Military training frequently produces heterogeneous landscapes. Large portions of military training areas remain virtually untouched, favoring disturbance-averse species; other portions are heavily disturbed, favoring disturbance-dependent species. The rich habitat mosaics include the two extremes as well as the continua of disturbance and succession between them, thus providing suitable habitat for a very large number of species with widely varying habitat requirements [21].

Nature in the impact areas is changing continuously. Those areas are open, whereas vegetation increases towards the edges of the target area. As the vegetation changes, so does the composition of species. In the open area, species that favor heat and dryness are common. Primary succession species of plants, which do not tolerate competition, are common. Many of these species, like Wild Thyme *Thymus serpyllum*, are important to rare insect species. The cessation of military activities has been found to decrease the amount of non-competitive species in the area compared to competitive ones [9]. To guarantee the maintenance of large open habitats, other management practices such as grazing and sod cutting are required.

Burnt wood as a result of military training replaces natural forest fires, especially in target areas. Therefore continuous forest fires due to shooting are important for the biodiversity of shooting areas. These areas with burnt wood provide habitat for rare insects (mostly beetles) and fungi species, which have disappeared from other parts of the country due to lack of natural forest fires. Studies conducted in Germany have found that transient fires in military firing ranges are useful in clearing vegetation for recolonization and habitat diversity. Soil micro fauna, important for soil function, was relatively unaffected by the fire or recovered rapidly [20].



Figure 12.2. Dead wood in Danish military training area.

Soil can compact because of heavy vehicles maneuvering. An increase of soil density and decrease of particle size lead to lower water infiltration. This could have negative effects on vegetation [12].

Erosion, soil compaction and destruction of vegetation in military training areas increase leaching of the soil. Leaching soil contains organic material, nutrients and in some cases contaminants like heavy metals and residues of energetic materials. Those can have negative effects on water bodies like increased sedimentation, nutrient loading and contamination. Some military training areas have been shown to damage the quality of water habitats [15].

### 12.3 Contaminants

Energetic materials (e.g. TNT, RDX, HMX) and heavy metals (e.g. Pb, Fe, Mg, Cu, Zn, Sb,) are the most common contaminants related to heavy weapons training. Explosions, low order detonations and pieces of ammunition shells are the main sources of contamination. In many heavy weapon training areas, small caliber weapons are also used. Heavy metals and energetics could contaminate soil and water bodies and have negative effects on habitats. There is no indication about ecosystem-level negative effects of soil and water contamination caused by heavy weapons training.

Mobility of heavy metals in the soil depends on temperature, pH, humidity, soil type and humic content. Heavy metals bound to organic material and their solubility is usually low [7]. Energetic material (EM) like TNT, HMX and RDX transform through different abiotic and biotic mechanisms. Biotic transformation of energetic material happens in both aerobic and anaerobic conditions. Degradation products of EM can be toxic or harmful, so it is very important to include those in any ecological risk assessment [19].

Lead (Pb) has been shown to disturb growth and reproduction of soil invertebrates. Lead could also bioaccumulate in predators when they eat prey [18]. Laboratory and field studies indicate that nitroaromatics do not bioaccumulate in the above-ground portion of plants or in the body of terrestrial wildlife species. It is unlikely that nitroaromatic compounds transfer between predator and prey animal species. RDX, on the other hand, accumulates in the subsurface and above-ground tissues of plants and it is possible that it will transfer from soil to plants and thus to herbivores [19].

Lead and TNT can have negative effects on soil microbes and other soil organisms. It can disrupt the ecological function of a soil system, inhibit natural attenuation processes and

destroy a portion of the soil microbial community involved in organic matter decomposition. RDX and HMX have little or no effect on soil microbial endpoints. Terrestrial plants are quite insensitive to the RDX and HMX. Lead, on the other hand, can interfere in the growth of vegetation. In general, the toxicity of energetic material and heavy metals for soil organisms varies and depends on both plant species and soil type [19].

EM affect classes of wildlife species in different ways. Mammals are more sensitive to exposure to nitroaromatics whereas birds, reptiles and amphibians are least affected. RDX is generally considered as the most toxic of the explosives for mammals because it targets nervous, hepatic and hematological systems. In birds, explosive compounds mainly affect the central nervous system and cause neuromuscular effects. Particulate white phosphorus ingestion has been known to kill ducks and swans. Based on a few studies, RDX is more toxic to reptiles than TNT and DNT [19].

In the risk assessment of the contaminated areas it should be considered that sometimes the remediation, especially excavation, can cause more harm on the nature than the contaminants. Risk to human health is main priority but regarding ecotoxicological risk the balance between the harmful effects of contaminants and the physical damage on organisms must be carefully assessed.

### 12.4 Impact of invasive species on shooting and training ranges

Invasive species are defined by the European Commission as “animals and plants that are introduced accidentally or deliberately into a natural environment where they are not normally found, with serious negative consequences for their new environment”. Long-term military training can increase the area’s vulnerability to non-endemic (invasive) species.

Typically invasive species are opportunistic and pioneer species. The plants adapt to utilizing recently opened areas. Therefore constructing a heavy weapons range, keeping it open and explosions creating areas with exposed soil make ideal conditions for an influx of invasive species.

Some introduced species do not pose a threat, e.g. if they are not able to reproduce due to climate conditions. In addition, the home range of animals and plants evolves and changes, which complicates distinguishing natural from human-caused dispersion. Therefore national authorities often evaluate whether new species will become a threat and create lists of invasive species. These can be used when deciding which species to combat on specific military training areas.

Limiting the spread of invasive species to new areas has often replaced the effort to eradicate them. Military operations pose a high risk of spreading invasive species. The equipment is regularly exposed to biological material. The same equipment is often used in different locations. Thus military equipment facilitates the human spread of species, even though this is unintended. To limit the spread of species, regulation is required to prevent military equipment with biological residue from being transported between areas.

## 12.5 Military training requirements for open areas

Military training requires open areas. Therefore, the military is advised to cooperate with nature management to find win-win solutions in which military activities are combined with efforts to keep the area open. In open areas, it is safer and easier, for example, to clear unexploded ordnance (UXO) and to supervise training.

Overgrowth is a typical challenge in military training areas. But it should be kept in mind that there is an opposite challenge in the cold regions: the recovery of vegetation is very slow and there is a risk of increased erosion.

There are numerous different methods to manage open areas. To find the most feasible method, you need to investigate and understand the overgrowth vegetation, the environmental conditions and the military restrictions. For each area there is a best practise for managing open areas and it is important to integrate it in the areal management processes. In Appendix 3E there is a more detailed description of the process for managing open areas.

## 13 IMPACTS ON CULTURAL HERITAGE

The definition of cultural heritage differs from country to country. Each nation has broad legal protections for cultural artifacts and sites. Cultural protection can be strictly focused on preservation, but it may also extend to accessibility.

Cultural artifacts can be of a highly diverse nature and can fall under different legal protection regimes. Even their potential presence and importance can vary across nations and sites. Therefore, to prevent significant damage the first step should be to conduct an analysis.

Certain military activities can damage cultural heritage, but with a relatively small degree of effort, cultural heritage can be preserved. The focus of this section is therefore on cultural heritage that is at greater risk of being affected by

military activities using heavy weapons. They can be divided into two categories:

- Historical artifacts (e.g. gravesites and traces of settlement)
- Access to cultural use of property (e.g. religious practices, traditional rites/rights of use, recreation)

Questions relating to the maintenance of protected, standing buildings, bridges or other infrastructure are not covered in this report. Biological or ecological units or dynamics that have been created through cultural practices such as land burnings and grazing are also not covered in this document.

Risk assessment of cultural heritage values begins with analyzing the likelihood of presence of culturally significant artifacts on the terrain. If there is a strong likelihood of finding artifacts, a contingency plan for accidental discovery can become of use and a more detailed study should be undertaken. What geographical information is available? What registrations on known artifacts can be compiled? What is the likelihood of unregistered or unmapped artifacts? In relation to larger scaled projects, a historical analysis for areas can be considered e.g. of impact areas or areas with a high fire hazard.

Based on the study, protection measures should be planned. These include map markings, safety zones on maps, instructions such as no-go zones possibly demarcated by poles or signs. A contingency plan should be formulated and communicated to key personnel.

The plan should include all relevant information on chain of events for the person it is given to (e.g. point of contact POC, what to react on, timing, actions in the field at sighting (registration, demarcation, full/partly stop of activity)).

Additional information about cultural heritage in the different countries can be found in Appendix 3B.



**Figure 13.1** Beech forest in Danish training area, which is also used for hunting.

## 14 RISK IDENTIFICATION

The flow chart in Table 14.1 is a recommended process for integrating nature and cultural heritage values into the management of shooting and training areas. For each of the steps, there are certain questions that should be answered. This process is a continuous cycle where, after monitoring and reporting, the process starts over, in order to see if the risks/impacts have been mitigated.

For the impact analysis and risk assessment, an example has been provided in Appendix 3D. The example is only for

the purpose of showing the risk identification process. This is a process for determining the nature and cultural heritage values and how different military activities will impact those values. Based upon this risk identification, determinations can be made for mitigation, compensation and/or enhancement, and then an action plan can be created, followed by a monitoring program.

A detailed description of risk assessment on cultural heritage values is shown in Appendix 3D.

**Table 14.1. Integration of Nature and Cultural Heritage Values into Heavy Weapon Range Management**

## 15 NATURE AND CULTURAL MANAGEMENT OPTIONS – BEST PRACTICES

When looking at best practices relating to the management of military training areas, it is not possible to make generic, but specific instructions. The chosen practice must always be found through a planning process that takes into account

the particular area in question and the particular military need. It is important to take an ecosystem-level approach in the management of military training areas that integrates soil, water, noise and forest issues.

## 15.1 Noise

Persistent high-level noise may cause changes in the animal behavior in order to be able to communicate amongst themselves. When the noise is more random (with silence between), it is much more difficult to see significant effects. In order to prevent noise impact, it is important to avoid noise during vital periods (e.g. nesting times) and sites (hibernation areas, vital nesting sites) instead of concentrating on the characteristics of the noise itself. Some species may be capable of adapting to military disturbance via habituation or learned tolerance. For a discussion about reducing noise in general, see Part II on noise.

## 15.2 Physical disturbance

When changing the training areas by physical disturbance, it is important to evaluate the size, timing and duration of the disturbance. As described above about keeping areas open, the disturbance can be both wanted and beneficial for the local area. When building new structures the project must be evaluated according to the regulations for the area. It is especially important to be flexible and creative when natural values dictate to find good alternatives to the original plan.

Another type of physical disturbance is the craters and other physical impacts from the training activity. The administrators of the training areas should spend considerable time deciding the location of target areas. These evaluations should include whether the areas should be smaller and more intensely used or bigger with less intensive use.

Open military areas are usually located in dry areas. Explosions and fires maintain the openness and offer a perfect environment for plant and animal species, which are adapted to dry and hot environment and/or are pioneer species (those which spread quickly but are not competitive species). Pioneer plant species can be a very important food resource for many threatened or rare insect species in Nordic countries.

If possible, rotating the target areas can give the plants time to spread to the exploded area, while another area is used as the target area. Rotation of target areas maintain the populations of certain demanding species within the area. Sometimes it is useful to import cut wood to the target area to maintain the continuity of burnt wood to sustain the rare species population.

Usually military personnel are trying to protect nature during the exercises by directing tanks and other vehicles to use certain narrow paths or roads. However, sometimes

nature benefits from this kind of heavy use. As mentioned earlier, certain pioneer plants need areas with minimal vegetation and considerable erosion. Random and scattered use of the area gives time for pioneer plants to grow and spread. Although some of them will be destroyed, this is beneficial for the whole population.

## 15.3 Fighting invasive species

Many conditions influence the amount and distribution of invasive species. Most important is that every single person will have to participate to solve the problem. Below are some examples of how to counter the spread of invasive species.

Clean equipment:

- Follow national regulations for cleaning used equipment (see Appendix 3F). Wheels of vehicles and other equipment carrying earth/mud between areas are of particular concern.
- Avoid transport of dirty boots between regions.
- Avoid transport of parts of plants (all food with seeds), insects and other animals between regions.
- Do not release animals (including live bait) into the wild.

Norwegian defense authorities have developed their own guidelines for transport of military equipment in and out of the country. These guidelines specify how to clean vehicles, boats, tools, personnel etc.

Inform about invasive species:

- Inform everyone about the threat from invasive species.
- Make sure everyone understands how they can contribute during their daily activities.

Remove invasive plants or animals:

- Arrange local task forces (soldiers, employees or other people) to remove invasive species. The more people taking part, the better the outcome.

In Appendix 3E there is more information about invasive species and how to fight them.

## 15.4 Best practices for managing open areas

In order to keep training areas open, human efforts have to replace what has traditionally been done by cows, sheep and goats through their grazing practices or by wild fires.

A management plan for the area that is meant to be kept open is needed to target the overgrowth. This will save time and costs. The management plan will also serve two other important issues. It will make it possible to continue the right action even if the responsible administration or the people working on it is changed. In addition it will serve as a reminder of the importance of updating the plan. That way it is also possible to change the effort together with the alterations made on the landscape. The list of species most responsible for overgrowth can and will change due to natural succession.

It is important to continuously keep track of the succession stages in the areas to make the right decisions about when, where and how to keep areas open. If an already open area is on its way to being overgrown, one has to adapt the effort according to the species in the specific shooting range.

One way to deal with the task of keeping areas open is to support grazing animals on the areas where this is still possible. It is also possible to use plant species that do not grow tall or fast.

Recent research in European countries (reported by the Norwegian Defense Research Establishment in 2016) shows that it may be possible to use grazers to stop overgrowth in shooting ranges. However, this demands detailed control of where they eat and how much soil the animals eat together with the plants.

Areas can be kept open through the use of several other techniques as well. Weeding is effective during spring/summer between fast growth and when the seeds are released. It is most important not to wait too long. If you are able to keep the vegetation at a low level, you should use regular cutting equipment (lawn mower and flail mower). If the vegetation has reached a higher level, more heavy machinery is needed (various lawn cutters, hedge trimmers, chain saws (electrical or petrol driven), etc.

The regulations on use of chemicals to erase vegetation (see also chapter on fighting invasive species) is differing between the European Union (EU) and non-EU members, e.g. Norway. Controlled burning may also be used to mimic natural forest fires.

In cold regions the recovery of ground vegetation is very slow and the risk of erosion is high, which has to be taken into account in managing open areas.

In Appendix 3F, the process of maintaining areas open is more thoroughly explained.

### **A procedure for how to keep areas open:**

1. Investigate thoroughly the species you are going to erase from the area; this enables you to prepare the correct method for further processing the landscape. Read advice about how to fight each species before you start the project. Search for advice about methods in national guidelines found in the following list: Norway: fagus.no, Sweden: movium.slu.se, Denmark: sl.kvl.dk (Videntjenesten), Finland (Ministry of Agriculture and Forestry). Then focus on the plant species that is most responsible for fast overgrowth.

2. Make a management plan in order to continue the correct activities. In the early stages of natural succession, the main action will be to keep the grass low. When you reach the next level, the deciduous forest species are growing fast. At this stage you will need more sturdy equipment, like a flail mower. A very few species demand the use of chemicals but restrictions on these are many. Also remember that regulations for the use of chemicals to erase vegetation (see chapter on fighting invasive species) differ between the European Union (EU) and Norway.

## **15.5 Cultural heritage**

Many countries have already centralized and formalized instructions and information about the protection of cultural heritage on military terrains, which can be an efficient way to engage with prevailing legal protections. There are plenty of examples where the military has had a beneficial effect on preserving historical names or landscapes. This, in itself, is valuable in relation to historical research and cultural identity, but as it is unlikely to be in conflict with heavy weapon use on training grounds, it is not included further in this report.

Protective actions in-situ to consider (coupled with analysis in Appendix 3E):

- Investigations to determine the presence of artifact, priority of artifact or protection needed (see Appendix 3D)
- Preventing fire and explosions on or adjacent to protected site or artifacts
- Ensuring safety zones, where activities are excluded, if no special permission is given
- Covering with cement to protect underground heritage
- Posting signs and markings (e.g. wooden or stone markers). In Sweden, there is a practice of using “Cultural stumps”, where stumps of a 1.3 m height are left in clear-cut areas to mark the presence of historical artifacts.

- Signs in the terrain should be adjusted to reduced visibility conditions (e.g. at night, from a tank, in high vegetation) and durability (e.g. if wooden poles are used in terrains with intense use of heavy machinery, a high maintenance level may be required). Enhancing the visibility of e.g. burial grounds could also be used.
- Fences or other closures of access points (e.g. obstruction of roads for lighter vehicles, guards)
- Moving artifacts
- Maps (with both military, nature and culture requirements)

### 15.6 Best Practice across management actions – communication, monitoring, planning

Across all the issues mentioned in earlier chapters, some elements are always relevant. These relate to proper communication, planning and monitoring practices.

Communication for sustainable management of military training lands consists of two key approaches; in-reach and out-reach. In-reach focuses on communication to the soldiers about sustaining the training lands and environment. Furthermore, it includes communication to the command leadership to assist in informed decision making.

Outreach is an on-going two-way relationship in which the military engages with a range of stakeholders. One element of outreach involves military organizations and personnel formally, informally, and routinely working with a wide range of key external stakeholder organizations about specific issues. The other key element aims to improve public support for the military and to increase public awareness about the military's training requirements and environmental stewardship. Everyone who works at an installation has the potential to contribute to outreach efforts. This proactive communication can help avoid overreacting to challenges and offer a framework for solving problems collaboratively when they do arise.

Successful planning for sustainable management of military training lands must include an integrated approach to include all necessary stakeholders. This can be accomplished with integrated management plans or training area use maps that highlight training requirements and natural/cultural resource requirements. The purpose of the integrated approach is to allow all stakeholders to state the respective requirements and de-conflict issues that would hinder meeting necessary requirements.

Finally, to measure the success of communication and planning, the results should be monitored. This includes reviewing in-reach or outreach materials to ensure that the correct audience is receiving the materials and that the content is current. For example, are different nations training at a location or has the training changed, such as using different weapon systems? In terms of planning, monitoring the environment (flora/fauna) is required in order to evaluate the success of the implemented plan. Adjustments can then be implemented to correct negative impacts as necessary.

#### Best Practice - Communication

Different best practices are recommended based on whether you are addressing people inside your organization (in-reach) or people outside the military organization (out-reach).

#### Best Practices for In-Reach

- Managers should receive appropriate education on the values of biodiversity, including mitigating techniques to minimize negative impacts.
- Land users should receive appropriate education or information in order to promote course of actions that minimize the negative impacts on natural and cultural resources. This includes information on the conservation of wildlife and plant species and applicable restrictions on related activities.
- Permanent information boards concerning the natural and cultural resources, as well as desirable behavior, may be installed at the gates of the military training areas. Temporary signs can be installed when extra caution is required in certain areas during specific time periods (e.g. breeding periods and nesting).
- Develop educational and awareness schemes for trainees, which may include the following:
  - Briefings prior to exercises, through which all participants are informed on the biodiversity of the training areas and of the mode of operation required to avoid negative impacts on the ecosystem.
  - Environmental training tools should also attempt to leverage information technology commonly used by soldiers. For example, integration of environmental training tools into mobile applications may widely increase dissemination.

### Best Practices for Out-Reach

- Create information boards to highlight the sustainable military training area management accomplishments. These can be displayed at community centers, schools or other venues to highlight the military stewardship of training areas.
- Create annual reports similar to the information boards that can be distributed to the public.
- Establish community connector events where the military engages with local community leaders to discuss training events, projects or potential issues.
- More information about communication can be found in Appendix 3G.

### Best Practice -Planning tools

- Integrated Natural Resource Management Plans (INRMP), utilized in the US Army, are an effective tool for capturing all the aspects of nature values. The integrated plan encompasses all the factors involved with natural resources in relation to the requirements for military training. The primary purpose of an INRMP is to ensure that natural resources conservation measures and military operations on the installation are integrated and consistent with stewardship and legal requirements.
- Integrated Cultural Resource Management Plan (ICRMP) is the installation commander's decision document for cultural resource management actions and specific compliance procedures. ICRMPs are internal compliance and management plans that integrate the entirety of the installation's cultural resources program with on-going mission activities, allow for ready identification of potential conflicts between the installation's mission and cultural resources, and identify compliance actions necessary to maintain the availability of mission essential properties and acreage.

## 15.7 Water management

Restoration of the natural water balance may benefit both biodiversity and military use. Many forests are ditched in Finland, for example, in order to dry the ground and to accelerate the growth rate of trees. By closing the ditches and returning the moisture to the ground, the spread of ground fires is prevented, or the speed of fire is decreased. They work as natural fire barriers. At the same time, the amount of deciduous trees increases, because deciduous trees tolerate moisture better than spruce and pine.

Restoration of mires has increased the amount of stored water in mire areas in Finland. Spring flooding on mires also serves as an effective fire barrier against dry forest areas near target areas.

There should be designated, less environmentally sensitive, places for troops to cross streams which can help, for example, minimize silting of the water. For some passages, it may be required to reinforce the bottom of the stream.

## 15.8 Timing of activities

Avoiding the most important breeding areas for birds during breeding season (timing depends on area and species) is important for successful breeding. One example is the Black Grouse lekking place in Syndalen, South Finland. From March to May, birds are lekking in the main target area. However, by establishing allowed shooting times, disturbance is avoided. Lekking happens from 3 am to 8 am, so not shooting until after 9 am protects the species. Birds move away for the rest of the day but return to near the lekking place in the late evening before dusk.

## 15.9 Further suggestions for improving nature values

Coniferous forests, especially young planted forests, are more sensitive to forest fires since they are drier than deciduous forests. Birch and other deciduous forests seem to prevent the outbreak of forest fires on many occasions. Due to this, e.g. Metsähallitus has increased the amount of deciduous trees by cutting small clear cuts in coniferous forests. The width of the clear cut is 1.5-2 times the height of the forest treetop. In this way, more sunlight reaches the ground and gives deciduous trees a possibility to grow.

The forest in the edge of the shooting area is left in a natural state. This means that the forest is diverse; i.e. there are different tree species and several layers of trees. The forest creates a natural barrier between the military area and private area. Thick forest not only hinders visibility, into or out of the area, but also reduces the amount of noise and dust from the military area. Deciduous trees also seem to prevent forest fires to some extent; at a minimum, they slow down the spreading of fire.

Artificially produced decaying wood helps biodiversity in the shooting area. Artillery shooting produces dead and burnt wood, which is crucial for many rare insect and fungi species. Usually dead wood is collected away from the area, but by leaving dead wood at the target area, it is possible to produce suitable microhabitats for rare species. Dead

wood can also be increased artificially by cutting the bark around the tree and letting it die slowly. When the tree falls down, it creates a natural open area in the forest where the light reaches the ground.

### 15.10 General overview of best practice

The following table shows a general overview of methods, practices and technologies, which can minimize potential conflicts between nature or cultural values and military training. Furthermore, a column with cost estimations has been added to illustrate various cost scenarios. It should be emphasized, that a cost-benefit analysis must be site specific.

**Table 15.1. Best practice for nature values and cultural heritage**

	Methods	Practices	Technologies	Cost
<b>Prevent damage from noise</b>	<p>Check with producers of the equipment for the possibility of adding technical solutions to lower the noise.</p> <p>It may be possible to make adaptations on the shooting ranges to concentrate noise in other directions, or to establish sound barriers.</p> <p>It might be possible to adapt training periods to less disturbing periods.</p>	<p>Check with local administration of nature management for which species should be considered and which period of the year the noise has to be monitored and possibly lowered.</p>	<p>If possible: Sound barriers, other types of equipment</p>	<p>Technical solutions to equipment: Various – depending on possible solutions.</p> <p>Sound barriers: Often very costly in order to have any effect.</p> <p>Adaptations on shooting ranges: Changing shooting direction can be done at relatively low costs if possible.</p> <p>Changing periods of shooting practices can be done at low costs, if other practice times are possible.</p>
<b>Physical disturbance (heat, pressure and burning)</b>	<p>Assess the relevant impact, as physical disturbance can improve natural succession but also cause damage in specific sites.</p>	<p>Assess changes in use.</p>		<p>Low. Assessments can be done at low costs. Mitigation costs might be higher depending on method.</p>

<b>Invasive species</b>	<p>Find and know the list of invasive species in each country.</p> <p>The exchange of equipment between regions has to follow regulations on import/export of equipment in order to prevent any spreading of invasive species.</p>	<p>Avoid spreading of invasive species by cleaning equipment.</p> <p>Do not transport any organic material between regions.</p> <p>Arrange local task forces to remove invasive species.</p>		<p>Low: To avoid spreading of invasive species is a relatively low cost compared to costs of removing invasive species.</p> <p>High: Fighting invasive species can be very costly and some species are impossible to remove when introduced.</p>
<b>Managing open areas</b>	<p>Find out which species are causing fast overgrowth in your area.</p> <p>Make a management plan to continue the work.</p>	<p>Use grazers, mowers or controlled burning to reduce overgrowth.</p>	<p>Fences, machinery or fire.</p> <p>For areas with high UXO risk remote controlled and/or armored machinery can be used.</p>	<p>Fences with grazers can often be established at relatively low costs, but it is very site specific.</p> <p>Machinery costs can be low or medium depending on site conditions and machinery. Armored or remote controlled machinery is often more expensive.</p> <p>Controlled burning demands much manpower, but is more effective than machinery i.e. it can be done less often.</p>

<b>Saving cultural heritage</b>	<p>Find out which historical artifacts or other cultural heritage values are known in your area.</p> <p>Find local information on how to protect them.</p>	<p>Keep historical names of sites.</p> <p>Inform personnel of how to react, if artifacts are found, i.e. stop activity and inform POC.</p> <p>Prevent fire and explosions on or adjacent to protected sites or artifacts.</p>	<p>Signs, folders, maps etc. to inform military personnel</p>	<p>Information can be distributed with relatively low costs.</p> <p>Preventing damage on artifacts or sites can be high, low or medium depending on training and shooting needs.</p> <p>Excavation of historical sites is high cost, but needs to be done only once.</p> <p>If historical sites are damaged, artifacts etc. might be impossible to reconstruct.</p>
<b>Improving communication</b>	<p>In-reach: education of managers and land users</p> <p>Information boards</p> <p>Briefings prior to exercises</p> <p>Out-reach: Improve public awareness about military's training requirements and environmental stewardship.</p>		<p>Mobile application tools to inform soldiers on nature values and how to avoid negative impact on ecosystems.</p>	<p>Information costs are relatively low depending on method.</p>
<b>Keep training areas suitable for training while protecting biodiversity in general</b>	<p>Use long-term planning tools.</p>	<p>Involve all relevant stakeholders to consider both military mission, natural and cultural requirements. Update management plans regularly.</p>		<p>Costs of updating management plans and involving stakeholders takes time and depend on costs of manpower. It can be done at various costs due to various levels of detail.</p>

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**PART IV**  
**CONTAMINANT**  
**MANAGEMENT**

## 16 INTRODUCTION

All training activities with munitions will result in some environmental impacts. Munitions are fabricated from many materials that, in sufficient quantities, pose an environmental risk [70, 78]. Knowledge is the most important factor in minimizing this risk. There are many factors contributing to range contamination, such as what munitions are used during training, where they are used, the quantities that are used, and the efficiency of the munitions in consuming their reactive components. In addition, the efficiency of the methods used in disposing non-functioning rounds or excess training materials is an important factor in maintaining the environmental health and sustainability of a training range. Inadequate environmental protection may endanger the training possibilities and subsequently the ability to maintain combat readiness.

Training with live munitions involves the use of many potentially contaminating substances. For the purpose of this report, the following will be considered: metals, pyrotechnics and obscurants, and energetic materials such as propellants and explosives. Munitions contain varying amounts of these substances but may not contain all of them. Accurate information on the identity and quantity of munitions consumed during training will give the range manager a grasp of potential sources and locations of con-

tamination. Even practice rounds may be a source of contamination. Practice rounds contain metals and, if fired, will expend propellants. They may also contain a small amount of explosives and pyrotechnics.

## 17 CONTAMINANTS AND CONTAMINATION OF HEAVY WEAPONS TRAINING

### 17.1 Contaminants of concern

Every munition is composed of many potential contaminants. All heavy weapons munitions contain metal parts. These are, for the most part, metals that are commonly found in the environment, such as iron and aluminum, but other, more toxic metals such as copper, chromium, tungsten, uranium, and beryllium may also make up a munition. If the munition is fired, propellant will be involved. Traditional propellant components are nitrocellulose (NC) based, with other compounds such as nitroglycerine (NG), dinitrotoluene (DNT), and nitroguanidine (NQ) [86]. Fine particles of aluminum are also used as a propellant component. An oxidizer such as ammonium perchlorate (AP) may be added, especially to rocket and missile propellants, to enhance the burn rate. Lead is also a component of some propellants. Different contaminants of concern are listed in Table 17.1.

**Table 17.1. Contaminants of concern**

Metals	Propellants	Explosives	Pyrotechnics and obscurants
Iron (Fe)	Nitrocellulose (NC)	Trinitrotoluene (TNT)	Hexachloroethane (HC)
Aluminium (Al)	Nitroglycerine (NG)	Hexogen (RDX)	Anthracene
Copper (Cu)	Dinitrotoluene (DNT)	Octogen (HMX)	White phosphorus (WP)
Chromium (Cr)	Nitroguanidine (NQ)	Pentaerythritol tetranitrate (PETN)	Red phosphorus (RP)
Tungsten (W)	Ammonium perchlorate (AP)	Dinitroanisole (DNAN)	
Uranium (U)	Lead (Pb)	Nitrotriazolone (NTO)	
Beryllium (Be)			
Zinc (Zn)			

Explosives are a component of most combat munitions, with the exception of penetrator rounds. Traditional high explosive (HE) compounds include trinitrotoluene (TNT), hexogen (RDX), and octogen (HMX) [78]. These can be combined with other compounds into formulations that are in widespread use, such as Composition B (Comp-B). Also, pentaerythritol tetranitrate (PETN) is a commonly used energetic compound in booster charges and demolition explosives [54]. Newer insensitive high explosive (IHE) compounds are now being introduced, including dinitroanisole (DNAN) and nitrotriazolone (NTO), both of which are less sensitive to shock and heat, making them safer for storage and transport, and in combat [41]. These also are combined with other substances and used in insensitive munitions (IM). AP has been used in several recent IHE formulations. The potential for contamination from various training scenarios will be examined in the following chapters.

## 17.2 Contamination of ranges

Contamination levels on ranges are a sum of many factors. These factors include: the efficiency of weapon systems and munitions, level of exposure and also temporal factors. Intact unexploded ordnance (UXO) is a potential long-term point source, whereas a low-order or partial detonation releases a significant amount of energetics into a small area causing more immediate effects [73, 84]. Local conditions and seasonal changes will determine the release of available contaminants. Wet environments accelerate contaminant transport, whereas dry climates reduce the transport rate.

Surveys of training ranges in several nations have found consistent results for similar weapon systems in terms of soil contamination. Mortar and howitzer projectiles filled with high explosives (e.g. Comp B, TNT) that detonate properly do not contaminate impact areas. However, projectiles that do not function properly will leave a significant mass of the explosive filler at their points of impact.

The soil at firing points for mortars and howitzers contain residues from propellants, specifically low part-per-million

concentrations of 2,4-DNT and nitroglycerin, except where excess propellant has been burned on the ground. Artillery propellant disposal areas, where excess propellants from training are burned in the field, may contain high concentrations of propellant energetics and heavy metals such as lead. Anti-tank rocket ranges have high concentrations of explosives (e.g. HMX) near the targets and of propellants (e.g., nitroglycerin) behind the firing line.

The soils at hand grenade ranges contain residues of RDX and TNT that are generally at low concentrations except where duds were ruptured in “render safe”-operations. The most highly contaminated ranges are demolition ranges due to unconfined detonations of C4, and other activities, such as munitions “render safe”-operations (breaching) that result in the incomplete consumption of energetics [48].

Some sites of special concern are listed in the Appendix 4D.

## 17.3 Propellant residues

There are two main sources of propellant contamination – residues from firing a round and residues from burning excess propellants. Firing point (FP) residues are a function of the efficiency of the weapon system and the composition of the propellant. Burn point (BP) contamination is a function of how excess propellant is burned. Knowing the potential source of contamination can assist in mitigating propellant residue contamination on ranges.

Propellant residues at FPs can vary widely, depending on the weapon system [76, 86, 88]. Larger weapon systems tend to be more efficient when fired. The longer barrels and type of propellants contribute to efficient consumption of propellants through longer resident times under heat and pressure. Rifled weapon systems (howitzers) are more efficient than smooth-bore weapon systems (mortars).

Disposal of excess propellants, if done improperly, may be highly contaminating. Propellant is designed to deflagrate when unconfined, so when disposal is by detonation rather than burning, the effect is to scatter most of the propellant

Residues from firing a 155-mm round will be half that of firing a 9-mm pistol round (1.2 mg vs. 2.1 mg), even though over 5100 times as much propellant is used when firing the larger round. Firing an 81-mm mortar round from a smooth-bored tube will result in 1000 mg of propellant residues, over 800 times as much as for a 155-mm round. The dispersion area for the 9-mm pistol is 16 m<sup>2</sup>, for the 81-mm mortar it is 150 m<sup>2</sup>, and for the 155-mm howitzer it is 900 m<sup>2</sup>. Along with the number of rounds fired and the deposition rate (DR) of the propellants per round, the dispersal area will determine the concentration of propellant residues at the FP.

over a wide area. Burning propellant on the ground, especially very wet or snow-covered ground, can also be inefficient, with up to 20% of the propellant remaining after a burn [85]. A poorly designed or maintained fixed burn pan for excess propellants can be a significant source of contamination not only from propellants but from heavy metals that may be incorporated in the propellant formulation or included in the propellant charges as a decoppering agent for rifled gun barrels.

### 17.4 Explosives residues

The way the round functions at the impact point determines the mass and extent of contamination. There are several ways of determining the functioning of a round. Efficiency

of a round is measured using the percent of energetics consumed during a detonation, as measured by explosives residues recovered on the ground following detonation [89]. A dud is a non-functioning round that has not expended any of its explosive material. On the opposite end of the spectrum is a high-order detonation, during which 99.99% or more of the HE is consumed. In between are low-order and partial detonations. Low-order detonations consume 75% up to 99.99% of the HE as residues. Partial detonations occur when the fuze functions but the HE filler does not initiate. Breached UXO have also been observed on impact ranges. These occur when a dud is impacted by fragments from a properly detonating round, resulting in penetration of the body of the UXO and exposure of the HE filler. Dispersal of contaminants is usually directly related to the functioning

A few examples will illustrate the mass/dispersal relationship. For 155-mm Comp-B rounds, a single duded (non-functioning) projectile will leave as much residue on an impact area as over a million high-order detonations (6600 g vs. 0,0059 g for 155-mm Comp-B rounds) [87]. A low-order detonation, which may consume 75% of the energetic material, may result in as much range contamination as 280 000 high-order (99.99%) detonations. The areas over which the detonation residues will be dispersed will also vary enormously. For the howitzer round, the residues dispersal area will be on the order of 1000 m<sup>2</sup> for a high-order detonation or a blow-in-place (BIP) operation, as compared to less than a square meter for a UXO or a few square meters for a breached or partially detonated round (fuze does not initiate round). Contaminant concentrations can thus vary from  $5,9 \times 10^{-6}$  g/m<sup>2</sup> for a high-order detonation to 650 g/m<sup>2</sup> for a breach round with a dispersal area of 10 m<sup>2</sup>. BIP operations can be relatively clean, approaching that of high-order detonations for conventional explosive formulations, but not all types of BIPs operations function efficiently.



Figure 17.1. Dud on the ice

of the round, with high-order detonations having a wide area over which a small mass of energetics is dispersed, whereas a dud or breached round has all the original mass of the round concentrated in a very small area.

Training on demo ranges also has the potential for high concentration of contaminants, especially as most of the explosives used will be unconfined. Chunks of C4 explosives from the inefficient detonation of blocks of C4 are common on these ranges. These chunks can be exposed to the weather and have the potential to break down and dissolve in rain. Practicing “render safe”-operations, which involve breaking open a munition to prevent it from being fired or initiated with the fuze, will also scatter large chunks of energetics on the surface of the range. Demo ranges have been found to be the greatest source of groundwater contamination on several ranges in North America.

Disposal sites can be a significant source of contaminants. A wide variety of ordnance may be disposed of on these sites using the same location, such as a pit or bermed area. Improper disposal of items such as propellants, fuzes, and demolitions munitions will result in high concentrations of contamination.

## 17.5 Metals

All heavy weapons munitions, and some propellants contain metals (Al, Pb). Most of the metal in a projectile is either iron or aluminum, which are commonly occurring elements in the soil. However, some munitions, especially older munitions, rockets and missiles may contain more toxic heavy metals. The metals deposited on ranges will initially be in two forms: fragments (or intact sections of munitions) and fine metallic debris.

The larger fragments, munitions parts, and UXO are relatively easy to clean up if access to a range is feasible. Fine particulate metal and metallic dust are not. Metallic dust is the result of the use of penetrators and shape charge munitions. The metals involved (copper, tungsten, nickel, and uranium, among others), are extremely toxic when inhaled or ingested. Ranges containing these metals can be a threat to environment and human health. An acidic environment may mobilize metals, and a wet environment can facilitate the transport of metals to groundwater.

Shaped charges and cargo ammunition (cluster munition) contain copper. At disposal sites, destruction of these types of ammunition can cause dispersal of significant quantities of copper [83]. High concentrations of lead have also been observed on sites, where small arms ammunition is destroyed.

## 17.6 Contamination distribution patterns

The nature and extent of contamination from training with military munitions varies based on several factors. The weapon system is obviously important, as is the type of training involved. Deposition areas for propellants at FPs have been established for many weapon systems [84, 88]. Propellant residues from anti-tank, rocket, and missile weapon systems will be behind the firing position rather than in front. Mounting the weapon on a vehicle, such as a 40-mm automatic grenade launcher on an infantry fighting vehicle, will confine the residues mostly to the vehicle. Qualifying ranges will have more concentrated areas of propellant residues compared to maneuver ranges because of fixed firing positions at qualifying range FPs.

Impact range contamination distribution patterns are dependent on target arrays and mode of fire [87]. Direct fire ranges have concentrated fire on a small number of targets. Indirect fire ranges have targets scattered around a large area, with the fire concentrated on those targets. Overlapping fire may occur with several weapon systems, resulting in a mixed distribution of explosive and metal residues. To this mixture residues from BIP operations may be added. Range contaminant loading depends on the reliability and efficiency of the munitions fired into a range. For example, a 60-mm mortar round has been observed to have a dud rate approaching 20%, and a 120-mm mortar round has been observed to have a low-order detonation rate of 12%. To effectively manage a range for environmental protection, it is critical to know what is being fired into a range and how it is detonated. Munition accountability will be discussed later in chapter 21.2.5. Typical contaminant emissions for different weapons systems are presented in Appendix 4A.

In addition to the caliber of the ammunition, several factors affect the munition efficiency at the firing point and impact area. For example, ammunition that is fired from a weapons system with a long, rifled barrel, such as a 155-mm howitzer, results in far less propellant residue than that fired from a weapon with a short, non-rifled barrel, such as a 60-mm mortar. Confinement enhances consumption of the propellant. Additionally, recoilless munitions, such as anti-tank rockets, do not confine propellant burn within the barrel of the weapon system, which can lead to high levels (>10%) of unburned propellant ejected from the rear of the launcher.

Munition initiation affects the amount of residue deposition. An improper impact angle of a munition on the target may lead to the malfunction of the fuzing system. The shape-charge warhead of an anti-tank rocket which does not hit a target squarely can shear open and spread explosives residues. Air-burst white phosphorus rounds leave

less residues than point-detonating rounds since they do not penetrate the soil, where moisture will attenuate the burning process.

Other factors that affect the efficiency of detonations include the mass, confinement, and shape of the explosives. A large mass of explosives that is confined in a large diameter, thick, hardened body with no square edges will leave much less residue than an equivalent rectangular mass of unconfined explosive. These factors are especially important at demolition ranges, where blocks of C4 are used for various operations.

### 17.7 Emerging munitions

New munitions and weapons systems are constantly being developed to address ever-evolving threats. In the Middle East and Afghanistan, the safety of stored munitions and resupply for forward operating elements has been a critical issue, with many casualties and loss of materiel caused by asymmetric attacks. To reduce the occurrence of unintended initiation of munitions, insensitive high explosive formulations have been developed. The detonation performance of the rounds closely mimics that of conventional munitions, but the munitions' sensitivity to impact, shock, and heat are all superior to conventional munitions' properties.

Insensitive munitions (IM) are a source of emerging contaminants on training ranges. Current munitions have been shown to be less efficient than TNT or Comp-B rounds during detonations, leaving high (>10%) quantities of some IHE compounds following high-order detonations [91]. BIP operations are even more problematic [92]. Environmental detonation testing of this class of munitions has not been completed, but data indicates that IM, although much safer to store and transport than conventional munitions, are a greater risk to range sustainability.

Research has been conducted to develop green alternatives for C4 in BIP operations. A new moldable explosive PAX-52 (Picatinny Arsenal Explosive) consists of HMX (instead of RDX) and silicone oil, which is less harmful for the environment but possesses comparable energy output to C4 [31].

Green Munition research and development has been going on for several years, but there is no ready-to-use options available. Canadian RIGHTTRAC (Revolutionary Insensitive, Green and Healthier Training Technology with Reduced Adverse Contamination) is a program aiming to show that green and insensitive munitions have better properties than current munitions. It is also feasible to implement safer weapon solutions that would ease the environmental pressure on ranges and training areas and decrease the

health hazards for the users. The goals of this program were to reach a near-zero dud rate and to eliminate the potential for RDX contamination as well as the use of toxic and carcinogenic compounds [29].

Compounds such as ammonium perchlorate (AP), a very water soluble toxic substance, and NTO, a highly acidic compound that will mobilize metals, can have a negative effect on the environmental sustainability of a range. Life cycle assessments of munitions containing these substances do not consider mass and distribution of post-detonation (including BIP) residues resulting from training with these munitions [99]. The IM family of munitions, as well as the new Green Munitions, should be field tested to determine mass and extent of post-detonation residues deposition before being fielded to avoid adverse impacts on range sustainability.

### 17.8 Pyrotechnics and obscurants

Pyrotechnics and obscurants are commonly used on training ranges, either as dedicated rounds (smoke rounds, flares) or as components on direct-fire munitions (tracers). Pyrotechnic devices produce light and sound. They contain various metals and oxidizers. Many pyrotechnic devices contain perchlorate; the largest threat of contamination would be from improper disposal of excess pyrotechnic devices.

Depending on the composition, pyrotechnic smokes can contain hexachloroethane (HC), zinc, TNT and anthracene [46]. Also, pyrotechnics and obscurants may contain heavy metals or pyrophoric substances such as white phosphorus (WP), which is toxic and may be very persistent in the environment [33, 93]. The amount of metals released to the environment during pyrotechnics training is sufficiently low to be indistinguishable from natural background unless the training is intense in one location for an extended time [33].

White phosphorus is a pyrophoric element used as an incendiary and an obscurant. When WP ordnance detonates, the white phosphorus auto-ignites and burns furiously. However, burning particles that fall into water, snow, or wet soil will extinguish [93, 95]. WP is extremely toxic in the environment and will persist for an indeterminate amount of time if it is covered by water or other factors that prevent sublimation. The best management control for WP is to forbid its use in wetlands, when the ground is covered with snow, or when it is raining. Because of its toxic properties, the use of WP is avoided in several countries. Red phosphorus (RP) – a common replacement of WP – has no tendency for self-ignition.

## 18 GUIDANCE VALUES

Guidance values are commonly used for regulatory purposes, but they are also useful for environmental maintenance of a site and decision making. Emissions caused by military training can be monitored and controlled by referring the resulting emissions to substance-specific guidelines. Internationally accepted and implemented guidance values are set for the most toxic, persistent, and bioaccumulating substances. Generic guidelines for numerous harmful substances have been assessed for soil, groundwater, surface water, and sediment as well as for air emissions. Many of the national guidance values are not legally enforceable standards, but merely informal technical guidance to assist state or local officials and site managers.

The bases of the guidance values may vary significantly. For instance, generic values are protective to all environmental media and human health and thus may be impractical for decision making at the site management level. Often guidance values are further defined according to land use (residential, industrial, recreational, military), or they may be separated into ecological and health-based values. Exposure route specific benchmarks can be used when monitoring harmful substances in drinking water.

Guidance values can be assessed to low threshold level, or they can be set to represent the highest acceptable concentration of the substance. Also, a guidance value may indicate the chemical concentration of individual analyses, or it may mean the annual average of the chemical load into the receiving water body.

Therefore, when selecting guidance values for range management purposes, the fundamental objectives of the guidance values as well as the site management goals must be clearly understood.

## 19 RISK IDENTIFICATION PROCESS (RID)

### 19.1 Environmental risk

Environmental risk can be defined as the probability of a sensitive receptor /recipient being exposed to a substance for sufficient duration to cause adverse (acute or chronic) effects [30]. Extensive literature on risk assessment methodology can be found in international journals as well as in various national and organizational reports [28, 33, 35, 45, 79, 90, 82]. Moreover, risk assessment of energetic materials, including both health and ecological aspects, has been thoroughly discussed in numerous publications for more than a decade [34, 48, 68, 70, 79, 81, 83].

In short, for health and/or ecological risk to occur, three fundamental components must coexist:

1. Source of contamination (mass, bioavailability, and concentrations relevant to cause risks)
2. Transport/exposure route (from source to receptor)
3. Receptor/recipient (with adequate doses and exposure time)

In general, if any of these three components are missing, risk cannot be verified. However, sometimes the existence of a significant contamination source without confirmed transport routes or receptors may warrant mitigation measures. In addition, the quality of groundwater or surface water may need to be protected, regardless of whether humans or fauna are exposed (i.e. the groundwater or surface water body itself may be the sensitive receptor).

In order for environmental protection measures in military training to be reasonable and cost-effective, the range management strategy should be based on scientific risk-based approach where all the relevant contamination sources, transport routes and receptors are identified.

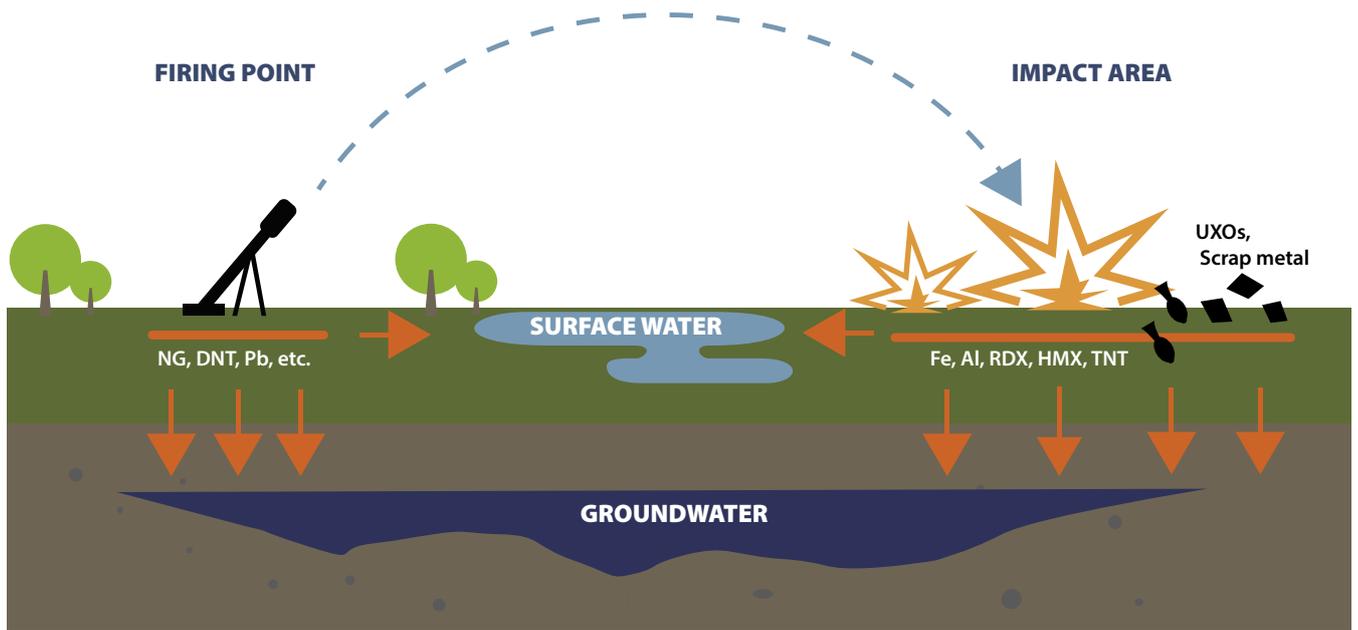
A proper risk assessment, however, is a multidimensional and complex procedure, which often consists of numerous uncertainties and assumptions, thus requiring specific expertise. Therefore, this project has developed a simplified Risk Identification process (RID) to support decision making and range management for heavy weapons shooting and training activities.

### 19.2 Use of the RID

The Risk Identification process is a baseline analysis of the possible risk-causing factors at a given training range. In the Generic Conceptual Model (GCM) of the range, military activities and coexisting environmental values are composed in the same large-scale “map” for management purposes (see Chapter 3). Since GCM includes several different sites, a general risk classification for each site can be formulated using the RID process.

The RID approach has similarities to basic concept of risk assessment and it is designed to be a flexible and repeatable process. The RID can have different levels, and it can be built up from a simple, qualitative risk screening into a more sophisticated, quantitative risk assessment. The RID can be made of a rather small amount of data on site conditions. With additional site information based, for example, on more detailed investigations, the process can be repeated and adjusted as many times as needed for the range management.

As a fundamental element of the RID, a more detailed site model for each site is developed. All the main components of normal risk assessment (source, transport and receptor)



1. Source of Contamination				2. Transport			3. Receptor			
Weapon system	Sub-site / Desision Unit (DU)	Chemicals of Consern	Soil Medium	Direct contact	Vertical	Horizontal	Ground-water	Surface water	Nature values	Human**
<b>Mortar (81 mm)</b>	Firing point (0,5 ha)	NG EC DNT	Gr, Sa	●	●	●	●	●	●	○
<b>Mortar (81 mm)</b>	Impact area (10 ha)	TNT* RDX HMX metals	Sw, Si	●	●	●	●	●	●	○

\* Degradation products of TNT (2- and 4-AT, DNT, TNB...). \*\* worker, residential, recreational

**Figure 19.1. RID-model of a site for a selected weapon system (mortar).**

should be identified and described (Figure 19.1). The RID should take into account the training activities (mortar firing point, etc.), local conditions and the potential land use of the site and its surroundings e.g. for recreational and residential purposes, including groundwater intake, gardening etc.

In the RID process the evaluation of site-specific conditions and receptors that affect the risks on the given site are based on a Traffic Light rating, i.e. using color codes (green – yellow – red) for indicating potential risks. Explanatory pre-conditions for such an evaluation and the resulting actions are given in Appendix 4B.

From a management point of view, there should be as few Red Light ratings in the RID as possible. If any of the assessed environmental media or receptor is rated Red,

it should automatically lead to follow-up actions such as additional investigations, potentially followed by risk assessment and/or ecological survey. After the additional actions have been carried out, a re-evaluation of the situation should follow until the rating can be changed to Yellow or Green. However, if the risks are considered unacceptable even after the more detailed investigations and re-evaluation (i.e. the rating in RID is still red), there may be a need for risk management and/or mitigation measures.

A Yellow rating in RID indicates either a need for additional data or underlines the fact that the possibility of ecological or health risks cannot be entirely ruled out. If the conclusive evaluation indicates Yellow for any of the environmental compartments or receptors, a monitoring program should be designed to follow-up the corresponding impacts of heavy weapon training on site.

A Green rating means that the receptor does not exist at the site or the environmental characteristics are such that neither significant emissions nor contaminant transport are likely to occur. A Green rating can also mean that, based on the site investigations or environmental monitoring, there is no significant amount of elevated concentrations of harmful substances on the site. Also, the weapon system or certain training can be considered Green.

The three components of the RID (source of contamination, transport and receptors) are described in more detail in the following subsections.

### 19.3 Source of contamination

For each weapon system the sites are delineated according to the areal extent of the possible emissions of contaminants. These sites can serve as designated study areas for environmental investigations. For example in mortar shooting, both firing point and impact area need to be evaluated as individual sites. On the other hand, when a propellant emission pattern is evaluated at sites where anti-tank rockets are fired, the whole distance from firing point to target must be considered.

It is important to assess the type and amount of harmful substances that are likely to cause contamination during training at the sites. The main focus when identifying contamination-causing substances should be on energetic compounds and metals. Those substances in the RID are called the "Contaminants of Concern" (CoC). Summaries describing munition constituents, propellants and metals in military formulations have already been discussed extensively in earlier publications [62]. The most commonly detected substances on military ranges with their physicochemical properties and environmental relevance are listed in Appendix 4C.

Typical contaminant emissions for different weapon systems are presented in Appendix 4A. It is important to note, however, that in the case of duds and partial detonations – not uncommon for certain type of weapon systems - delayed or abrupt release of most of the munition constituents to the environment are likely to occur and thus must be taken into account. Furthermore, the site may have (or may have had) multiple uses whereby several weapon systems are fired on the same firing point or impact area. Therefore a variety of different CoC and emission scenarios may have to be considered. However, the first version of RID can be processed without exact knowledge of CoC of the weapons system.

In addition, the quantity of the chemical load at the site should be estimated to some extent. Usually there is a register of the rounds fired at the site, as well as the cal-

endar of the shooting days per year, which can be used to compose a general picture of the utilization rate of the site. Importantly, bookkeeping of low orders and duds is essential when assessing the chemical load and accumulation of energetics at the site.

Oftentimes some environmental investigations have already been done at the site. In such cases, the existing environmental data can be utilized in RID by comparing chemical concentrations to chemical specific guidance values.

### 19.4 Transport

After defining the site, identification of the CoC and the chemical load, the transport potential is identified based on the site-specific conditions (types of soils, depth to groundwater, distance to surface water, surface water flow paths, vegetation etc.).

The physicochemical properties of different munition constituents and metals determine the environmental behavior of the CoC. Some environmental characteristics of CoC are listed in Appendix 4C. If any energetic substance or propellant is selected as CoC, the existence of potential transport routes – instead of transport potency – must be assessed first. When needed, a more detailed fate and transport assessment based on the environmental chemistry of the CoC can be done in a quantitative risk assessment.

Potential transport routes (vadose zone flow/leachate, surface water run-off and groundwater flow) are identified and rated for their environmental significance (Traffic Lights), based on the geological and hydrogeological characteristics of the site (prevalent soil type, vegetation, ditches, groundwater status etc.) Even though the soil type is not rated, it must be categorized because of its important role on the vertical and horizontal transport of the substances. As indicated in Appendix 4C, environmentally relevant and abundant substances on military ranges are not readily volatile. Thus, the Traffic Light rating is primarily based on the potency of the substance to cause risk by transport through soil to surface and groundwater. If the soil type and the type of weapon system used can result in accumulation of the CoC in the top soil of the site, a direct contact to soil may be assessed as a transport and exposure route.

### 19.5 Receptors

In toxicological risk assessment, a receptor is often defined as a living organism (flora or fauna, human) that is exposed to a CoC via a specific transport and exposure route. In the RID, all environmental compartments (surface soil, surface water, groundwater) can be the potential recipient of the emission.

Classified groundwater areas, Natura 2000 areas and defined areas of ecological conservation (endangered species) are examples of recipients that should be automatically considered. The human receptor (worker, residential, recreational) directly exposed to a CoC, or indirectly affected by heavy weapons training, can be identified. At this point, Traffic Lights ratings indicate whether or not there is a possibility for the receptor to be exposed to a CoC caused by particular heavy weapons training.

The Worker-receptor represents either maintenance workers, military personnel or conscripts who are repeatedly working/training at the site where there is constant emission of the CoC (dust, top soil, water) for a long period of time (from months to years). A Residential-receptor is considered if the site is located at a groundwater area and the water is used in an adjacent municipality (waterworks) or other designated use (private household wells) for tap water, irrigation etc. A Recreational-receptor may get exposed when camping, swimming, picking berries, hunting etc. at or near the site that is also used for military training.

When assessing the Traffic Light rating for receptors in the RID, the exposure scenario should be realistic. For example, if a heavy weapons impact area is considered, it should be clear that there is no direct exposure to human receptor at the site (no access to the area). Also, workers directly in contact with chemicals are usually following Health and Safety protocols and are using personal protective gear.

At this stage, no effects assessment of the exposure will be done. In the effects assessment, toxicological and ecotoxicological characteristics of the CoC are included, and therefore this type of assessment is done only when the decision has been made that the site should go through a detailed quantitative risk assessment. Before the effects assessment, it is often advisable to execute additional environmental investigations (soil, water, sediment). It is recommended that any detailed evaluations of chemical fate, transport and exposure scenarios should be done with input from environmental specialists.

## 19.6 Concluding remarks on the RID

In conclusion, the RID can be used to identify risks and set up ratings without detailed environmental data and surveys about the site conditions. Information about the type of weapons used, number of rounds fired per year, number of years fired, EOD and clean up-practices, groundwater status and surface water areas, as well as important nature reserves should be readily available for most ranges. The process needs a baseline reflecting the historic use of the range. This may or may not affect the risk associated with future activities.

There are many important factors (chemical concentration in soil and water, environmental and toxicological characteristics of CoC, depth to groundwater, soil stratigraphy and composition, hydrogeological circumstances, precipitation and weather conditions, local populations of endangered and/or protected flora and fauna) which will be necessary to define if the rating of the site indicates the need for a quantitative risk assessment.

Once risks have been identified, practical recommendations for range management are given. The most common management recommendations resulting from the RID are additional soil and water investigations and adjustments in the monitoring program. Risks can sometimes be avoided or minimized by modifying the training site with environmental protective structures or by moving the training to a less risky location. In the case of acute risk or detected contaminant transport to groundwater, the only management option may be the remediation of the site. Also, risk assessment plays an important role in assessing site-specific remediation methods and determining the clean-up goals.

Risk identification and conceptual modeling as part of risk assessment provide qualitative and quantitative information for decision making to implement practical and cost-effective approaches on range management. Site-specific risk identification is an essential step when the potential need for further risk assessment and/or risk management on a site is being evaluated. Also, this approach makes it possible to prioritize the sites for their risk management, mitigation needs and scheduling.

## 20 CONTAMINANT MANAGEMENT OPTIONS

After the Risk Identification (RID) process, the most common management recommendations are soil and water investigations and adjustments to the monitoring program. Risks can sometimes be avoided by simple management controls when sensitive areas are avoided and certain areas have rest periods. Training areas can be modified with environmental protective structures or runoff water collection and treatment. In the case of detected contaminant transport to groundwater, the only method can be remediation of the site.

### 20.1 Site Survey

#### 20.1.1 Investigations

In this document, an investigation is defined as an action where the concentrations of one or more compounds or environmental conditions are measured at the site of interest. The sampling area and the compounds are chosen based on the goal of the survey or according to regulatory

demands by environmental authorities. Measurements are done on soil, water (surface/ground water), air (soil gas/atmosphere), sediment, receptors (flora, fauna) or a combination of these. Measurements can be done either in the field or on samples taken to a laboratory for further analysis.

There are many reasons why an investigation is conducted. There can be a need for a baseline study (development of new range), monitoring programs, risk assessment towards a receptor (during operation of a range), part of a remediation effort or maybe to create documentation during the closing of a range. Because a specific investigation will only be able to answer a specific question, it is very important to carefully consider which question you are trying to clarify before setting up and conducting a survey.

Typically investigations are too complicated to be performed by the end user of the range and will require the assistance of environmental specialists. It is recommended that surveys be conducted according to NATO's task group report "Munitions-Related Contamination – Source Characterization, Fate and Transport" [62] where sampling objectives and strategies, sampling protocols and analytical methods are presented in detailed level.

### 20.1.2 Monitoring

In this document, monitoring is defined as an action where the concentration of one or more CoC is measured at specified points at regular intervals (hourly/daily/weekly/monthly/season/yearly). Measurements are typically done on soil, water (surface/groundwater), air (soil gas/atmosphere) or a combination of these. The sampling points and the measured CoCs are chosen based on the goal of the monitoring. Measurements can be done either in the field or on samples taken to a laboratory.

There are no specific guidelines how to monitor different military ranges. Monitoring must always be designed for the specific range because every site will have a unique setting (including geology, climate and CoCs). Typically monitoring is too complicated to be performed by the end user of the range and will require the assistance of environmental specialists.

Environmental permits usually include monitoring programs or demands, but it is not always mandatory to apply for an environmental permit for military training ranges. Monitoring is often planned to understand better the environmental condition of the range and also as a baseline



**Figure 20.1. Soil sampling in impact area**

study for risk identification processes. Monitoring is often conducted to document that there is no unacceptable transport of contaminants outside the range, but there can be also other reasons why monitoring might be necessary.

Some important points need to be considered when developing a monitoring strategy for a range:

**Establishing the reason for monitoring, which could include:**

- Protecting groundwater/surface water for drinking
- Protecting habitats for plants/animals
- Protecting lakes/streams/rivers that provide food for humans
- Quantifying leaching from a specific area
- Taking a proactive approach: preventive actions before guideline values are reached

**Establishing a monitoring strategy/program:**

Data quality objectives

- Where to monitor: main recipient (e.g. fish in the lake), source (e.g. the impact area), pathways (e.g. rivers, lakes)
- What medium to sample: water, soil, air, receptor
- Which chemicals to measure/analyze: metals, energetics, some selected compounds, all possible contaminants including degradation products
- How to sample: obtaining samples (Multi-increment sampling, water samples), passive sampler over longer periods
- What are the action levels: what is the concentration level that requires action, and which actions are necessary
- When to stop monitoring or revise the monitoring plan.

## 20.2 Management controls

Different management controls are presented briefly in this chapter. More specific information and references can be found in Appendix 4E, Descriptions of management options.

### 20.2.1 Siting and range planning

Heavy weapons ranges should not be located at sites where the risk of impact on the environment is unacceptable [63]. Experience from many ranges has identified a number of key issues that always should be taken into consideration:

Avoid siting new activities on groundwater protection areas. Avoid siting ranges or impact areas near surface water bodies (lakes, streams). A buffer zone of at least 100 m is recommended.

- Avoid areas with surfaces that are prone to erosion, sheet erosion, flash flooding or other kinds of excessive runoff caused by poorly absorbent soils.
- Do not use impact areas that have hard surfaces or outcrops that cause unnecessary fragmentation of projectiles.
- Establish designated areas for different activities, like fixed firing positions
- Establish fixed target areas only where the conditions are right.

Risk and vulnerability analysis (RVA) is a systematic method for assessments of the risk of adverse incidents. Risk is an expression of the danger that the adverse incident represents to people, the environment or material values [63]. Such a method can be implemented in both the planning process and management. A Canadian tool [60] identifies critical areas through an overlay of three maps: A *Vulnerability map* identifying sensitive areas like aquifers, a *Hazard map* describing the pattern of deposition of munition constituents (MC), and a *Risk map* identifying critical areas where MC migration may reach groundwater and surface water.

### 20.2.2 Fixed target areas and firing points

Fixed target areas and firing points provide opportunities to amend migration of CoC at a reasonable cost but may not be an optimal solution in cases where the location is not suitable or because of the impact is too heavy for a small area. Vegetation might be destroyed and the surface become subject to erosion. Structures preventing vertical or horizontal chemical transport could be set up at fixed, contained sites like hand grenade ranges, antitank firing points and targets, OB/OD ranges.

### 20.2.3 Erosion control

Erosion of the topsoil will become a problem if the vegetation in an area disappears. This typically happens in fixed target areas where repeated impact of projectiles will wear away the vegetation and thereby leave scars in the vegetative cover. If possible it is recommended to rotate between target areas so that the natural vegetation has time to regenerate between shooting periods. Erosion increases the transport of CoC from the top soil. When contaminated soil is physically disturbed by vehicle maneuvering and digging, this increases the risk of contaminants leaching.

The use of heavy vehicles, in particular tracked vehicles, might create areas without vegetation, where erosive processes can become active. The loss of surface vegetation, together with compaction of the top soil, decreases the pore air and water movement in soil, which further increases erosion on the impacted area. It is recommended to designate and clearly mark the tracks where maneuvering heavy vehicles are allowed, so that the impact on vegetation can be reduced and controlled.

Erosion on ranges might be a result of human or animal activity. Animals such as cows, sheep, goats, and reindeer might create widespread erosion as a result of intense grazing. Animals can also be exposed to chemicals because they often ingest large quantities of soil when grazing. This should be considered if grazing animals are allowed to go into impact areas or firing points.

#### 20.2.4 *Rotation of ranges, rest periods*

Natural attenuation processes can be used in range management by varying the location of training activities. By designating rest periods between training activities, the excessive accumulation of residues can be minimized. Fixed firing points that are used intensively could receive propellant deposition at a higher rate than the environmental conditions degrade it, resulting in an accumulation that presents environmental risks to receptors and the potential migration of propellant residue to surface or groundwater.

Likewise, impact areas have fixed targets. In addition to target placement away from vulnerable areas, rotation of the fixed target areas would allow the surface disturbance from detonations to revegetate. Also, during the rest period of the impact area, photolytic and microbial activities together with weathering effects actively degrade MC in top soil and surface water.

Significant residues from low-order detonations would need additional mitigation such as periodic inspection for and collection of solid residues [49].

The length of the recommended rest period will depend on local site conditions, the type of ordnance that is used in the activity and the intensity with which it is used. This method is not applicable to ranges where the ordnance fired has a high deposition rate or the residue is persistent in the environment.

#### 20.2.5 *Record keeping*

Accurate information about prior use of a range is important for a number of reasons. This includes both safety, potential contaminants and total load of MC. However, records are

often incomplete or missing. In addition to looking through historical records, an accurate recording of the present use is essential to help proper current and future use. Therefore, proper record keeping procedures should be established and followed. For ensuring adequate accuracy of reporting, a quality check system should be established.

#### **Reporting requirements:**

- Date of shooting/training
- Quantity and type of rounds fired (preferably LOT-number)
- Firing point and target area
- Number of duds and low-order detonations
- EOD clearance procedures (where, how many, procedure)

Not all munitions fired into an impact range function correctly. Duds (UXO), partial detonations, and low-order detonations may occur, resulting in the deposition of large amounts of energetics on the range [36, 37, 87]. With UXO, these energetics are sealed within a metal casing that may take decades to be released into the environment, or they may be breached by frag from a nearby detonating munition, exposing a large mass of energetics to the environment in a very small area (square meters). Tracking and removing malfunctioning rounds and UXOs is important to ensure range sustainability. Management controls need to be put in place to ensure accurate records of what is fired into a range as well as how many rounds malfunctioned so actions may be taken to remove or reduce these high-concentration sources of range contamination.

#### 20.2.6 *Propellant burn pans*

Propellants will generally be left over from artillery training. Excess propellants may occur at burn points (BPs) on the ranges. Burning can be done in fixed burn pans in the field or at a centralized location, or in portable burn pans that can be located near active firing points (FPs). Soil and surface water contamination have been detected near old fixed-field burn pans (no maintenance, improperly used) and BPs. These contaminants include lead, NG and DNT which are all toxic substances. To prevent soil, surface water and groundwater contamination, the use of portable burn pans or a well-maintained centralized fixed burn pan should be mandated by the Range Manager or Environmental Officer. Burn pans have been shown to be very efficient at consuming propellants and avoiding contamination of the soil with unburned propellant residues. Use is easily controlled and only minimal intervention by personnel is required for the portable burn pan. Operation manuals are available for both types of pans [76, 77, 78, 85, 86, 90, 97, 98].

## 20.3 Engineering controls

### 20.3.1 Washing stations

Weapon systems and armored vehicles are washed after training. Wastewater may contain oil, metals and energetics. As a rule, washing vehicles and tanks in the natural ponds, lakes or water ways should be avoided.

Cleaning can take place in washing stations located at the garrison. Such stations may include pressure washers, concrete sedimentation reservoirs and water recirculation systems with oil skimmers. Often it is rational to wash the equipment at or close to the training range. In such cases, attention should be paid to proper wastewater management. For instance, wastewater can be collected with a liner covered with permeable stone material, for instance 40 cm of crushed stones. Water is infiltrated and collected in sand traps, and/or it is sent to a collecting well for particle separation and then either to a well filled with a specific filter medium (see later “filters”) or thermally treated peat. There is also a trailer-based filter which can be used to pump up water. Flow speed must be slow to ensure sufficient time for the water to react with the filter media.

### 20.3.2 Berms and sand traps

Berms and backstops are generally recommended for stopping and capturing small arms bullets. This is also a valid

method for field firing ranges. Berms designed for larger calibers have a different function, especially if the rounds contain exploding charges. The impact from larger projectiles throws up a lot of soil along with munition residues. Heavy weapons special features (shock wave, penetration) should be taken into consideration when planning these structures, so that plastic or bentonite liners designed for infiltrating water collection are not damaged. For this reason, is it not advisable to combine small arms and heavy weapons berms.

Shooting in bunkers or sand traps is suitable only when using training ammunition for heavy weapons and therefore this is not considered an appropriate technology for contaminant management.

### 20.3.3 Water management and treatment

Heavy rain and late winter snowmelt conditions cause both increased water flow and increased transport of contaminants. This has implications for using all types of engineering controls. Some measures should be designed for storm water episodes while other measures will be designed for normal flow because this situation is more stressing for the local water ecology.

Contact between water and munition constituents is the main cause for corrosion, dissolution and migration of contaminants into surface and groundwater. Landscaping on a larger scale can be used to separate surface water and



Figure 20.2 Washing station



**Figure 20.3 Regulation dam installed.**



**Figure 20.4 Regulation dam in use.**

drainage pathways from impact areas. Small streams, for instance, may be redirected around firing ranges. It is important to observe national regulations regarding restrictions on disturbing waterways.

Solutions for water treatment must be designed according to both water flow and actual contaminants. In most countries, local conditions like frost, drought and precipitation must be considered before a solution is chosen. Water treatment facilities require a specialist to plan and construct them because of the complexity of the task. The daily handling and maintenance, however, might be conducted by staff on the range. Engineering solutions such as liners and clay layers can be used as barriers to prevent infiltrated water from reaching the groundwater. Both bentonite and plastic liners can be used. Maintaining an intact vegetation cover inside and around a target area is a good preventive measure to mitigate surface water transport of particle contaminants. Identifying the flow pathways and installing obstacles that can trap

sand and silt should be standard-design components. The installations can be permanent or temporary.

When surface water pathways are identified, several types of installations can capture contaminants adhered to particles. These include:

- Sand filters
- Vegetated areas that slow down the water flow and capture smaller particles (see constructed wetlands)
- Infiltration ponds that use the soil as a filter
- Sedimentation ponds.

On a smaller scale, surface water can be protected by bypassing polluted areas through a pipeline. Firing ranges are often disturbed by brush fires and a constructed wetland may serve as a reservoir for firefighting.

### 20.3.3.1 Surface runoff fields

Plain low-yield bog areas with a low gradient are best suited for surface runoff fields. In such areas, water velocity is reduced when water spreads evenly across a large surface area, percolating through the surface peat and vegetation. Good results have been achieved with surface runoff fields not only for the removal of solid matter but also nutrients [44]. Indications that surface runoff fields can also retain heavy metals are provided by a number of surveys conducted in the mining industry [65].

Common wetland plants with an excellent capability to uptake heavy metals include broadleaf cattail (*Typha latifolia*) and bur-reed (*Sparganium*) [51]. In biofiltering tests, the above-mentioned species have been found to uptake zinc, copper, lead and cadmium particularly well. Research also shows that biofilters with canary grass, willow and purple loosestrife uptake zinc, copper and aluminum work effectively [71].

Fields operate best in summer when the biological processes that occur in them are most efficient. Surface runoff fields can also be used together with other water protection structures, such as sedimentation basins and flow-control structures. Suitable sites for surface runoff fields are large impact areas, demolition ranges and disposal ranges.

### 20.3.3.2 Constructed wetlands and settlement basins

Constructed wetlands and settlement basins are structures that are used to separate or filter contaminants from water. Wetlands should be primarily established in areas that are naturally wet, such as overgrown ponds and meadows subject to frequent floods. A wetland area should be located

so that it can be established principally by damming or constructing an embankment.

A settlement basin is designed to slow down the water flow so that gravity will allow small particles to settle to the bottom. In constructed wetlands, reed beds are commonly used for the same function. The water flow can run both on the surface and subsurface and be both horizontal and vertical. This means that root system and microbiological activity can contribute in binding metals and breaking down organic components.

Constructed wetlands and settlement basins of varying size are sometimes useful in trapping contaminating chemicals that have been mobilized by flowing water. As the flow carrying the contaminant passes through the wetland/basin, some or all of the particles in the water will potentially settle in the bottom sediment. Contaminants attached to organic particles are not likely to settle and other measures must be used. This requires that the contaminant is particulate in matter and that the speed of the water flow is sufficiently slow during its passage through the wetland/basin. A potential challenge with this method is the possible concentration of contaminant in the sediment, which at some point might require clean-up and possibly treatment.

Capturing metal residues in constructed wetlands downstream of remediated closed small arms ranges has been attempted as a low cost amendment. A few of these projects have been reported and evaluated by the Norwegian Defence Research Establishment [58].



Figure 20.5 Settling pond with biofilter

### 20.3.3.3 Filters

Adsorption onto solid media can be used to remove heavy metals from both surface and groundwater. The technology is simple: it is a fixed-bed process where metals and other anions are adsorbed onto a packed bed of media. Small arms ammunition residues contain mainly lead, copper, antimony and zinc and few adsorbents have the ability to remove them all from water [57]. Several types of adsorbents have been tested and it is possible to select an adsorbent based on which metals are of the highest priority to remove [58].

The efficiency of the filter is related to the contact time, which should be at least fifteen minutes. The adsorbents are, in general, costly and the water should therefore be collected as close to the source as possible to limit volumes. High organic content in surface water may rapidly reduce the effect of the filter and makes filtering less suitable on field firing ranges than on qualifying ranges for small arms.

If runoff is collected from a limited target area like a stop berm on a small arms range, the normal flow may be less than 1-2 liter per minute, which means that a filter can be installed at a reasonable cost.

### 20.3.3.4 Monitored natural attenuation

Monitored natural attenuation (photolysis, microbial degradation) can effectively mitigate explosive residue in top soil and surface water. TNT has been shown to be readily degraded by a variety of micro-organisms both in aerobic and anaerobic conditions [23, 43, 75]. However, significant mineralization of TNT has not been shown to occur [50].

Degradation and anaerobic mineralization of RDX in laboratory and mesocosm experiments have been reported [32, 43, 69] and aerobic mineralization has been reported due to utilization of RDX as a nitrogen source by bacteria [40].

Explosive compounds are degraded chemically and abiotically by hydrolysis, oxidation, reduction and photolytic processes. TNT, RDX and HMX are not readily degraded by hydrolysis except in highly elevated pH conditions [25, 26, 47].

Photolysis is an important mechanism for TNT, RDX and HMX transformation in the environment [72]. Especially in surface waters, phototransformation of explosives is an effective process in reducing the environmental impacts [61]. TNT is readily degraded from water when exposed to natural light such as in surface waters, while RDX is resistant for degradation. TNT and RDX are not readily degraded by abiotic degradation under dark conditions [22].

According to a study of phototransformation by sunlight using chunks of TNT and RDX over three years, the loss

of material was significantly higher than was recovered in dissolved mass taking into account possible error sources, such as handling, analysis and material sublimation. Hence, significant amounts of products may be formed also in natural systems that are not currently known. [74].

### 20.3.3.5 Ultraviolet irradiation

Ultraviolet irradiation (UV) is a frequently used purification and disinfection method at the municipal waterworks. UV-irradiation has been shown to degrade TNT and RDX concentrations from the test water, but not efficiently enough for UV to be used as the sole treatment method for MC-contaminated water at waterworks [22]. Also another study has shown that UV radiation is not efficient for complete degradation of TNT, RDX or HMX [53]. Thus, UV method is generally used in combination with other remediation methods, such as oxidizers or reverse osmosis [24]. The cost of UV-irradiation is estimated to be low, since it is commonly in use in various industrial and household applications.

## 20.3.4 Source remediation

### 20.3.3.6 Excavation

The most common way to handle soil contamination is by the simple method of excavation. The polluted soil is removed with an excavator and transported to a designated site which has permission to handle the contaminated soil. Excavation is often a practical solution at points with a manageable and very concentrated amount of contaminated material. Typical remediated areas can be stop berms or fixed target areas. EOD must be done before excavation.

Excavation is often a simple, reliable and fast solution, but there are several issues that might cause excavation to be a problematic choice. The amount of contaminated soil might be so vast that removing it is simply impractical. This is often the issue on military ranges where wide tracts of lands might be diffusely polluted with metals. If the groundwater table is close to the surface, digging might not be possible. There might not be any facilities which are able to cope with the amounts of contaminated soil being removed from a range, especially if the soil is contaminated with energetics. Treatment and disposal of contaminated soil needs environmental permission and waste management centers do not usually have permission to receive soils contaminated with energetic compounds. Explosives may not degrade using different composting techniques, but especially TNT will react and bind to organic material.

It must also be considered what the environmental effect will be from having large machinery digging and driving on the range. It might have a detrimental effect on the flora/fauna that surpass the benefits of reducing the contamination at the site.

### 20.3.3.7 IR-heater

If the contamination consists of energetics deposited on the surface (typically back blast area on antitank ranges) then an infra-red (IR) heater is a practical solution for remediation. IR radiation heats primarily the soil particles, thus being a more efficient method than heating the soil with a flame thrower, which heats the air. The contaminated area is heated by IR radiation and the temperature in the soil reaches a level where the energetics start to combust [38]. A problem with this method is the shallow penetration of the heat front into the soil. The soil has to reach temperatures of at least 200 degrees Celsius for the method to be effective. If energetics are buried more than a few centimeters into the soil, they will not degrade. Another drawback is the sterilization of the soil being heated, which destroys the local flora and microfauna in that area.

### 20.3.3.8 Manual removal (EOD)

Pieces of energetic material are collected and burned by EOD personnel at ranges to reduce the mass of energetic residues in source zones, preventing their dissolution and migration. This also helps with potential safety issue when people have access to large chunks of explosives.

### 20.3.3.9 Clean-up of metal using magnet

A high-power magnet can be used for cleaning the top soil of metallic debris. Depending on the soil type and debris, metal fragments can be pulled up from a depth of 5 - 15 cm. At many sites it is mandatory to do EOD before cleanup. Dense vegetation and rocky terrain may affect the speed and efficiency of such work.

### 20.3.3.10 Soil amendments

Attenuation of contaminants will be a function of the climate and soil conditions. Some compounds will mineralize, whereas others will sorb to organic matter. Attenuation processes are quite complex and are beyond the scope of this document. Carbon content and biological activity in the soils will affect biotransformation of some energetics. The presence of some forms of iron will significantly enhance the mineralization of energetics. High acidity (low pH) will affect the mobility of metals and impede biological processes.

The solubility of contaminants can be reduced by adjusting the soil conditions (pH, organic matter contents, or particle size distribution) by amendments. In general, dry, neutral conditions and soil types containing fines and some organic matter are optimal for minimizing the leaching of contaminants. Adding reactive materials to soil containing contaminants involves risks, as the reaction mechanisms of the different contaminants are not known well enough. Both excavating and modifying the chemical state of the top soil layer may release contaminants bonded to the humus. Therefore, the use of soil amendments always requires

careful planning. Soil amendments have not been tested on soils with high organic content.

For some of the products, it is recommended to use 2 - 5 % amendment. In many types of soils, it will be difficult to mix such a low quantity of amendment evenly into the soil. If the soil is difficult, the percentage might have to be increased to 20%. This will significantly impact the costs. The use of soil amendments is feasible only for relatively small areas.

#### Iron

Ferric compounds have been proven to be a good sorbent for the most common metals in ammunition residues: lead, copper, antimony and zinc [59, 64]. Ferric materials are available both as dedicated products but also as wastes from industrial production. These are potentially inexpensive products suitable for larger impact areas.

#### Organic material

Biological amendments to soil can adsorb and transform energetic compounds on military ranges. At the same time, their use will reduce the potential migration to groundwater or surface water. TNT can be reduced and can be irreversibly bound to the organic substrate, and RDX and HMX can be mineralized in optimal conditions. [49].

#### Clay

The contaminant-binding capacity of coarse (sandy) soil can be improved by adding fines like clay. Bentonite can be used to reduce the solubility of metals. Reducing the soil permeability by adding fines increases surface runoff, possibly increasing the impact on surface waters.

#### Liming

Alkaline hydrolysis (liming) involves adding hydrated lime to surface soils containing energetic residues. The increased alkalinity results in the transformation of TNT and RDX to less mobile products, reducing the potential for migration in the soil. Liming is an inexpensive approach for managing energetic residues in soil at hand grenade ranges and demolition ranges. Lime must be in liquid form to affect energetics and pH must be very high (11, 5), which can cause unwanted effects. Changes in the soil's pH can cause leaching of other contaminants and local soil conditions should be studied very carefully before using lime [49].

#### Phosphates

Phosphate can be used to bind contaminants, especially lead. There are large differences between different phosphate compounds with regard to their pollutant-binding capacity, and all phosphates are not suitable for the purpose. Phosphate-induced metal stabilization (PIMS) is a method utilizing phosphate additives that has been developed for the in situ treatment of contaminants in the

soil. The PIMS method uses Apatite IITM (U.S. patent no. 6,217,775). The suitability of other types of phosphates, such as tailings from apatite mines, for reducing the solubility of metals has not been extensively studied, and the results from those studies that do exist vary.

The use of phosphate compounds may cause surface water eutrophication and groundwater contamination, as the amount of soluble phosphates has been found to increase significantly in the water percolating through the soil after the addition of phosphate compounds [39, 52]. There are also some indications that phosphate amendments may increase the solubility of antimony.

#### 20.3.3.11 Phytoremediation

Phytoremediation has been studied for the treatment of high explosives, and it has been shown that plants can take up and transform TNT, RDX and other explosives [27, 55, 56, 66]. Although the exact enzymatic mechanisms have not been fully delineated, it appears that plants are effective at removing and transforming nitro-group containing organic compounds. These processes may include both plant degradation and the stimulation of microbial biodegradation of the contaminants. Common grasses have been found to be effective at removing NG and 2,4-DNT from hydroponic solutions [67]. The uptake of propellants by grasses may be a useful and inexpensive method for remediating contaminated soil and reducing leachate migration, especially behind anti-tank firing points.

#### 20.3.3.12 Fungus treatment

Using fungi in bioremediation has been of interest to scientists because fungus has the ability to produce several extracellular enzymes, including lignin peroxidase (LiP), manganese peroxidase (MnP) and laccase. These enzymes have the capability to degrade several types of chemical bonds. In the case of the wood rot fungi *Phanerochaete Chrysosporium*, mineralization of TNT is dependent on the physiological state of the fungus, being either lignolytic or non-lignolytic. TNT is reported to mineralize under the lignolytic condition and that state can be identified by the presence of peroxidase enzymes such as LiP and MnP. [43].

## 21 RECOMMENDATIONS FOR CONTAMINANT MANAGEMENT

It is recommended to always start by identifying and quantifying the potential environmental risks through a RID process (chapter 20). Based on the result of this process it is possible to focus on the most important issues and choose amongst the available management options on an informed basis. Every range is unique and will require a unique set of solutions to mitigate the environmental impact to the highest degree possible.

In the following paragraph a set of recommendations are presented to aid in the process of designing an environmental management plan for any heavy weapons range. These recommendations do not cover every possible option, but only those deemed most useful by the working group. It must be stressed that every range needs to have a specific range management plan to address environmental challenges.

### 21.1 Range management recommendations

Recommended standard procedures should be taken into account at all ranges. Section 21.3 presents possible additional measures, to be considered at high-risk sites. The following standard management procedures are recommended:

#### Siting and planning

- Avoid siting new activities on groundwater protection areas.
- Avoid siting ranges or impact areas in the vicinity of surface water bodies (lakes, vernal pools, streams). A buffer zone of at least 100 m is recommended.
- Avoid hard surfaces (rock outcrops, stones) in impact areas.
- Establish designated areas for different activities, like fixed firing positions.
- Take into account possible water treatment structures (water collection wells).

#### Record keeping

- Establish proper record keeping procedures. Always report:
  - Date of shooting/training
  - Firing point and target area
  - Quantity and type of rounds fired (LOT-number)
  - Number of duds and low-orders
  - EOD clearance procedures (where, how many, procedure used for clearance)
- Establish a quality check system for ensuring the accuracy of reporting.

#### Use of ranges

- Only use ranges for the purpose for which they are planned/accepted.
- Schedule site-specific rest periods within the fixed performance positions (e.g. firing positions, targets) to prevent build-up of contaminants and allow time for natural recovery.

- Do not use white phosphorus or ammunition containing white phosphorus in wetlands, near water bodies or on snow cover.
- Dispose excess propellant by using a proper burn pan. Do not burn propellant on the ground or snow.
- Do not dispose propellants or munitions by dumping or burying.
- Surface clear ranges prior to site work.
- Concentrate special training, like ice breaching, into one or a few sites.
- Establish a monitoring program.

### Range clearance (EOD)

- Establish periodic range clearance operations (munitions, explosives).
- Avoid “render safe”-operations, which will often result in low-order detonations scattering contaminants around. Training for “render safe”-operations should be done in areas designated for this purpose, e.g. demolition ranges.
- Avoid using C4 for blow-in-place operations due to RDX contamination risk. Use e.g. PETN or PAX-52.
- Do not leave ammunition or visible pieces of explosives on the range.
- Do not blow up propellant; burn it instead in a structure designed for that purpose.
- Do not bury ammunition or dump it in water bodies.

### Soil handling

- Do not excavate or move soil from shooting ranges (firing positions, target areas and berms) without consulting an environmental specialist.
- Before remediating demolition and disposal ranges, clear ordnance and explosives.

## 21.2 Additional management options

Environmental risks can be identified by the RID-process and these risks should be confirmed by detailed investigations and risk assessments. Range management recommendations should be evaluated first and use specialists help to assess if detailed planning is needed to prevent environmental impacts. Engineered options should be designed on a case-by-case basis.

Management options and technical solutions for different weapon systems and training areas are presented in Annex 4D and 4E and in chapter 20.3. The general level of costs is also evaluated.

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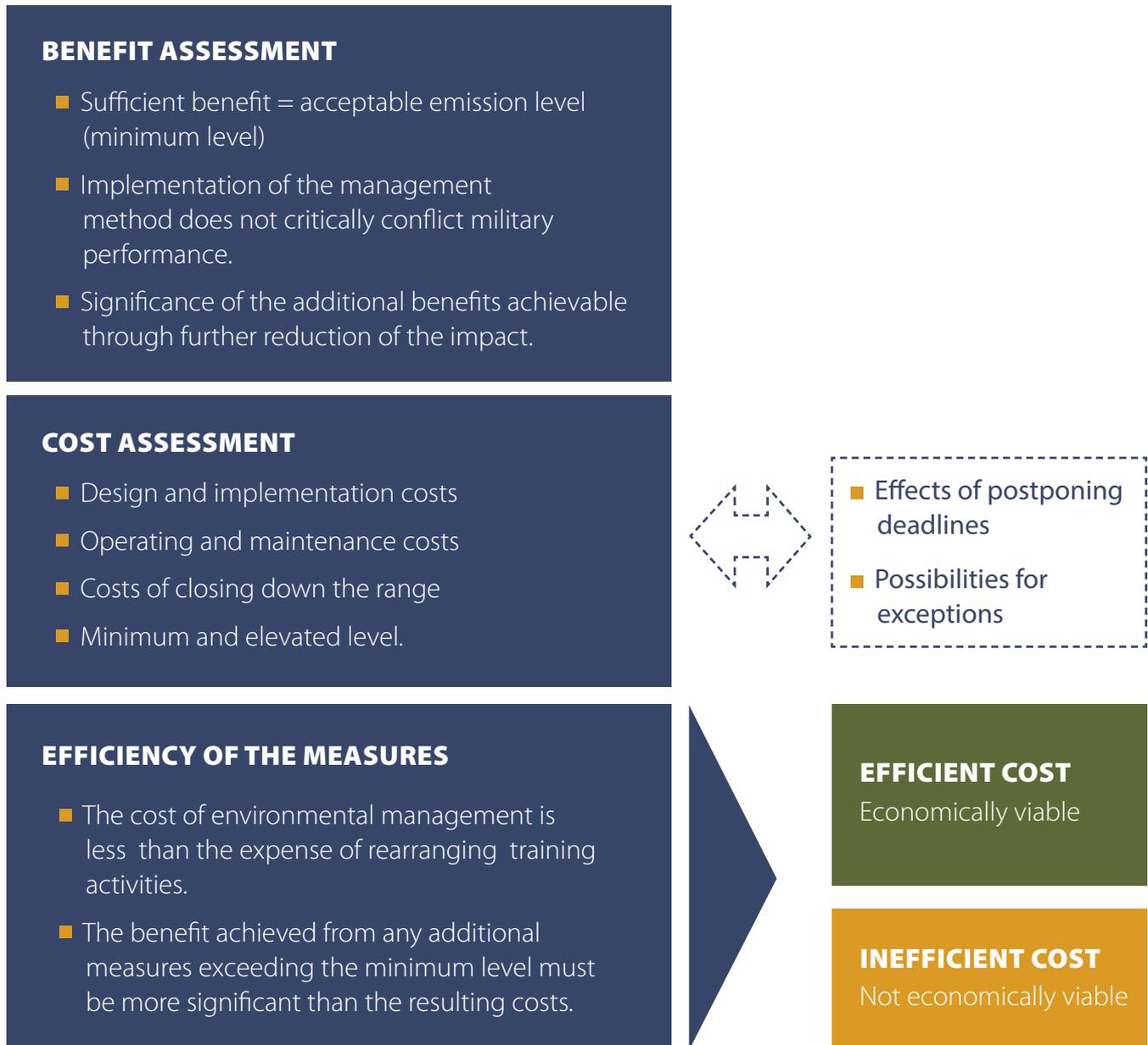
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# **PART V**

# **IMPLEMENTATION**

## 22 VIABILITY ASSESSMENT



**Figure 22.1. The principles of the viability assessment**

The environmental cost-benefit assessment is an important part of choosing the correct method for environmental impact management. The basic principle is that the environmental benefits should be sufficient and more significant than the costs.

The costs and achieved environmental benefits must be assessed on a site-by-site basis. A simple qualitative comparison between the methods is presented for each sub-topic in the previous chapters. For intangible methods, such as outreach or planning the training activities, it is difficult to put a price tag. These methods can be considered inex-

pensive and can be infiltrated in normal processes as long as the methods are otherwise feasible.

The benefits can be considered sufficient when the acceptable risk level is achieved. On the other hand, environmental protection should strive to mitigate and prevent environmentally harmful impacts beyond the minimum acceptable level. Therefore the significance of additional benefit relative to cost should be assessed for measures that exceed the minimum level and are possible to achieve with reasonable extra investments.

Part of the viability assessment in military areas is to consider whether environmental impact management could hinder or restrict the usage of the site for its original purposes. In other words, the measures should be designed so that they do not critically conflict with military requirements.

Before choosing an environmental protection approach, it is also vital to take into account all the environmental aspects as a whole. The three subtopics have been described in the previous chapters and they need to be thoroughly cross-examined before choosing risk management or mitigation methods. For example, if it would be beneficial to transfer some activities to another location for groundwater protection, it is important to make sure that this will not cause problems with noise or endanger sensitive nature values.

## 23 OTHER CONSIDERATIONS

### 23.1 Safety considerations

Heavy weapons ranges are commonly used intensively, which is why careful planning with personnel responsible for training is required so that the environmental investigations and any construction can be carried out at sites without posing a risk either to safety and occupational health or to the training schedule through unnecessary delays. The designed structures need to be examined by training and safety officers so that they will not compromise safety when combined with shooting and other training activities on the site.

Any unexploded or partially detonated ammunition on the heavy weapons ranges need to be removed before any physical management methods are used to address environmental impacts. Therefore it is necessary to consult EOD personnel in the planning process.

### 23.2 Communication and outreach

When thinking about managing environmental impacts of military training, there is value in broader military-civilian cooperation, going outside the boundaries of government personnel. The economic and social development can impact the military both in terms of the land the military uses (in this case, for training and shooting areas) as well as in the military's ability to execute its required responsibilities. It is necessary to maintain a balance between military requirements and social requirements through a process of constructive engagement, which is sometimes referred to as outreach, as described in Chapter 16. An outreach program brings together all the people who care about an issue (the stakeholders); they can come from the military, other parts of the government, non-governmental organizations, and the populace in general. They can be

landowners, environmental authorities, external experts and concerned citizens. An outreach program can help the stakeholders better understand each other's needs and find mutually acceptable solutions. An example of an outreach program is captured in US - South Africa co-work (*US-South Africa Environmental Security Working Group. Outreach for Mission Sustainability: Working to Balance Military and Civilian Community Needs, 2010. <http://www.denix.osd.mil>*.) The guidebook was written for the use by any country, describing a generic process for developing such a program.

Outreach may be necessary also within the military; outside the environmental branch the military personnel might still have misconceptions about what environmental protection really means and what its requirements are. This sort of outreach can also be called "in-reach". It includes e.g. internal reports, briefings, theme campaigns and education.

Communication is an effective tool to manage relationship with stakeholders. For example the irritability of noise can be greatly diminished by informing people about the shootings and having a functioning feedback system. Having community connector events is also a good way to involve the surrounding community, to inform about the training and discuss about potential issues. Project meetings between military, landowners and environmental authorities can be beneficial when planning site-specific impact management on a given shooting and training area.

Communicating actively about the environmental work diminishes possible worries people might have about how the environment is taken into account in the military training. Publishing annual reports and articles of environmental projects strengthen the trust in the defence forces as an environmentally accountable operator.

## 24 FURTHER DEVELOPMENT NEEDS

During the project, existing knowledge of environmental impacts of heavy weapons shooting and explosions was collected. The feasibility of possible impact management methods was assessed and a process to choose the correct approach to mitigate the impacts on a heavy weapons range was created. Some topics that need further study and development were also recognized.

### 24.1 General

During the project it has been shown that it would be valuable to have more cooperation between countries in order to learn from each other's best methods. Such cooperation, through the sharing of best practices and lessons learned, can save valuable time and resources.

The number of multinational exercises is increasing and hence the guidance for host and sending nation (HN and SN) support is getting more important. Having common understanding between nations about environmental practices and responsibilities is crucial for effective environmental protection and well-organized planning and execution of the exercise. Simultaneously with this project, another international project was launched to harmonize the HN and SN instructions for military training.

It would be beneficial also to look into possibilities to harmonize some aspects of legislation. For example guideline values could be set according the same policy. Soil and groundwater conditions vary but the principles how to take the conditions or land use into account should be the same. Also the basics for noise modelling should be unified and standardized.

## 24.2 Subtopics

### 24.2.1 Noise management

Health effects of noise have been mainly discovered in studies related to road traffic noise. Heavy weapons shootings do not take place continuously; therefore effects to health may differ from that of other types of environmental noise. Training takes place mainly at daytime, so sleep disturbance is not a significant factor.

More research is needed on noise from heavy weapons in order to better describe how this influences people's health.

Nations have defined different noise metrics for evaluating noise from heavy weapons. There should be internationally standardized guidance for the noise modelling. Today countries use slightly different calculation methods with some variation in parameters.

### 24.2.2 Nature values and cultural heritage management

Even though biodiversity surveys have been done, on some areas there is still lack of information on species and habitats that are present on the shooting and training areas. There is also lack of information of how the military activities affect the nature on an ecosystem level. This requires still further studies. One development topic could be to create a standardized procedure to compose a biodiversity survey and how to report the results.

The changing climate especially in the northern Europe is most likely moving towards a warmer and wetter climate. Under these conditions, the process of overgrowth is likely to speed up. This means that there will need to be greater efforts expended to keep areas open in the future.

### 24.2.3 Contaminant management

The Life Cycle Assessment procedure should be revised so that range activities with the munitions are included. Better round accountability is needed so that duds and low-order detonations can be assessed.

Assessed procedures should include:

propellant efficiency

detonation efficiency

realistic dud and low-order detonation rates and

BIP residues.

A remote sensing system should be developed, so that detonation types on impact ranges can be detected based on noise or pressure. In addition, a system should be developed to be able to identify corroded munitions and munitions buried in shallow soils. Different field analysis methods should be developed to detect explosive residues in soil and water. This would save time and money.

Information should be available in in usable databases; later this information can be used in modeling programs. This information can include open data about soil types, surface or groundwater levels and quality, weather data. In addition, detailed information about contaminant behavior is needed.

## 25 CONCLUDING REMARKS

In the current European security situation, Nordic and international military cooperation has become more and more important. Denmark, Iceland and Norway are NATO member nations and Finland and Sweden active NATO partner countries that participate in shared training events. Due to this development, it is vital that troops moving to train in another country have a shared vision of environmental responsibilities. In addition, in case of severe crisis, all countries must have the ability to give and receive help from member/partner nations and environmental requirements must be clear and uniform enough to support the mission at hand.

The use of heavy weapons is mostly a monopoly of armed forces and therefore the only possible benchmark on their environmental impacts is what other countries have achieved in this field. Nordic countries and Northern American nations share similar climate and environmental conditions. All Nordic countries, USA and Canada are forerunners in research of military environmental impacts. Nordic countries also share a rather similar environmental legislation.

The afore mentioned laid a solid basis for cooperation to create a report on environmental impacts of heavy weapons and ways of mitigating possible harmful outcomes. During the work specialists realized that varying working methods, national views, cultural differences and foreign language made it more demanding to produce such a manual than would have been the case in any one country. Nevertheless, it must be said that the project has brought the experts closer to each other, given all a wider view on matters and taught us all about good practices of others' and maybe also warned us from making the same mistakes that one of us has already done.

The purpose of this project was to collect and assess good practices and technical solutions for environmental risk management at heavy weapons ranges. The aim and target group of the document evolved during the project. Initially, the idea was to create a rather brief summary of current state of matters and provide practical tools for a wide audience from range managers to stakeholders. The final product is a solid stand-alone description of environmental protection possibilities in heavy weapons ranges, although it is not meant to replace in-depth handbooks in the field.

The project focused on the full range of environmental aspects, and is thereby probably one of the first attempts to bring the whole scope of heavy weapons training impact mitigation into a single presentation, including contaminant management, nature conservation and noise management. The project made an ambitious attempt to create a common framework to address various environmental aspects in a uniform manner. During the work it was realized that this common structure had to be adjusted to fit the special needs of the themes. All in all, it also brought specialist of different disciplines to same meetings and probably enhanced the overall understanding of many subject matter experts.

The main content of this document focuses on these three topical areas: what environmental impacts heavy weapons training causes, what practices and technologies could be used to might mitigate some of these impacts, recommendations for the impact management and also topics for further study and development. During the project it became clear that there are unnecessary differences and thus needs for standardization in some areas, for example noise modelling.

The common perception was that technical solutions and management practices that are used elsewhere in the society could to some extent be transferred, further developed and used on heavy weapons training ranges but there is not sufficient experience on their cost-effectiveness yet. The project tried to maintain a common sense view on matters

that highlights the practicality, economical feasibility and calls for adequate amount of real life proof of benefits of certain practices or technical solutions before their wide-scale use. Since there is a lot going on at the moment and several countries are testing new methods and solutions, this document should be revised periodically to remain useable.

After careful evaluation of the facts, it became clear that physical solutions are limited and at least today often not feasible. Another important area of interest was therefore the management and development of training practices that address the important goals of military training, but minimize their environmental impact. Quite often, the backbone of environmental protection on heavy weapons ranges remains careful reporting of activities and a sufficient monitoring of the environment.

# APPENDIXES

## 1 General

### Appendix 1A About the participants

This document was developed through the collaboration of subject matter experts from Canada, Denmark, Finland, Norway, Sweden and the United States. As with all such endeavors, any errors are those of the team members and do not reflect the official positions of any of the nations or their departments of defense. All contributors are listed in alphabetical order.

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Bo Larsson	Sweden	Nature conservation and civil-cultural specialist	Swedish Fortifications Agency
Philip de Lasson	Denmark	Geologist	Danish Defence Estates and Infrastructure Organisation
Mette Mygind	Denmark	Head of environmental and nature branch	Danish Defence Estates and Infrastructure Organisation
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Torben Pedersen	Denmark	Project officer	Armed Forces Denmark
Darja Poleshuk	Denmark	Administrative officer	Danish Defence Estates and Infrastructure Organisation

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<b>Øystein Valdem</b>	Norway	Team leader, noise and vibrations	Norwegian Defence Estates Agency
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<b>Michael Walsh</b>	U.S.	Senior research engineer (retired)	U.S. Army's Cold Regions Research and Engineering Laboratory.
<b>Matias Warsta</b>	Finland	Director of real estate and environment	Finnish Ministry of Defence

## Appendix 1B: Typical heavy weapon systems

- Mortars: muzzle-loaded, smooth-bore, high-angle-of-fire weapon.
  - 60 mm mortar
  - 81 mm mortar
  - 120 mm mortar
- Artillery Cannons
  - 105 mm cannon (towed howitzer)
  - 122 mm cannon (towed howitzer)
  - 130 mm cannon (towed howitzer)
  - 155 mm cannon (towed howitzer)
  - 155 mm cannon (turreted self-propelled howitzer)
- Tank guns
  - 105 mm gun (mounted on M1128 Mobile Gun Striker System)
  - 120 mm gun (mounted on M1 Abrams and Leopard 2)
- Cannons (mounted on combat aircrafts and helicopters)
  - 20 mm Gatling-type rotary cannon (like F-15, F-16, F-18, F-22). It is a hydraulically or pneumatically driven, six-barrel.
  - 25 mm Gatling-type rotary cannon (like F-35). It is a four-barrel.
  - 30 mm Gatling-type rotary cannon (like A-10 Thunder Bolt). It is a hydraulically driven seven-barrel.
- Cannons (mounted on infantry fighting vehicles)
  - 25 mm cannon
  - 30 mm cannon
  - 35 mm cannon
  - 40 mm cannon
- Anti-tank rocket weapons (portable, single-shot, shoulder-launched)
  - 66 mm Light Anti-Armor Weapon
  - 84 mm AT4
  - 84 mm Carl Gustaf recoilless rifle
  - 102 mm NLAW
  - 112 mm APILAS
- Anti-fortification rocket weapon (portable, single-shot, shoulder-launched)
  - 83 mm Bunker Defeat Munition
- Anti-tank missiles (mounted on a tripod or shoulder-launched)
  - direct fire at a tank or infantry fighting vehicle from a ground position
  - Tow and Javelin missiles
- Surface-to-air missiles (shoulder-launched or vehicle-mounted)
  - direct fire at an aircraft from a ground position.
  - Stinger missile.
- Surface-to-surface missiles
  - launched from the ground or the sea and strike targets on land or at sea
  - powered by a rocket engine or an explosive charge
  - launching platform is typically stationary or moving slowly
  - MGM-140 Army Tactical Missile System (ATACMS), cruise missiles (Tomahawk) ballistic missiles (Trident II D-5) and anti-ship missiles (Harpoon)
- Air-to-surface missiles
  - launched from military aircraft at targets on land or sea
  - most common propulsion systems are rocket motors and slower, longer-range jet engines
  - Maverick, ALCM, HARM, Hellfire, Penguin.
- Air-to-air missiles
  - fired from an aircraft for the purpose of destroying another aircraft
  - Sparrow, Sidewinder, AMRAAM

## 2 Noise management

### Appendix 2A: Measurement procedure and modelling input data

#### Measurement procedure

The measurement procedure is based on the German standard.

#### Instrumentation

- **Microphones:** The peak level from heavy weapons noise sources will depend on the distance from the source to the microphone position. In general, levels of more than 160 dB SPL<sub>peak</sub> should be expected when measuring close to the source. The handling of great sound pressure levels requires low sensitivity microphones. Typically, a 1/4" microphone is sufficient, with a sensitivity of 3 mV/Pa, thereby providing a dynamic range of approximately 40-170 dB. Secondly, it is important that the microphone has enough bandwidth to capture the signal. The microphone should be pointed perpendicular to the direction of the sound propagation (90° incidence) to minimize the diffraction effect.
- **Data Acquisition System:** The microphones and associated preamplifiers are connected directly to a National Instruments data acquisition unit for A/D conversion. The data acquisition unit is connected to a laptop storing the measured signals for later laboratory analysis. The output signal from the microphone preamplifier should fit the dynamic range of the data acquisition system to prevent overloading. The data acquisition process is controlled by a custom LabView program with integrated trigger control. The trigger is set-up to record 500 ms of data before the trigger.
- **Acoustic Calibration:** System calibration is carried out in the field before and after each test session using an acceptable acoustical means. A pistonphone or other similar standard source whose calibration is traceable to international standards should be used.
- **Anemometer:** An anemometer is measuring wind speed and wind direction at 10 m above ground level and as close to the test site as possible.

#### Measurement Levels

- Instantaneous Sound Pressure
- Sound Pressure Level
- A-/C-weighted Sound Pressure Level

- Peak Sound Pressure Level
- Maximum Sound Pressure Level
- Sound Exposure Level

#### Test Site Layout and control

- **Source Size and distance:** The distance between the microphones and the noise source depends on the weapon caliber.
- **Surface:** The measurements are performed on flat acoustically soft-ground sites, essentially level with no trees or other large reflecting objects within 50 m of any measurement microphone.
- **Measuring equipment placement:** The measuring equipment used for recording (data acquisition system and laptop) is positioned no closer than 7.5 m to any microphone to avoid reflections. If a large central recording facility is used, it shall be at least 50 m from the nearest microphone.
- **Control Source:** TNT is used as the control source. Source data are compared with the TNT measurements to correct for site- and weather-related variation, which would otherwise be included in the data. The size of the control TNT charge is keyed to the size of the weapon being measured.

#### Modelling input data

##### Emission

##### Blast

The muzzle blast is recorded in five different microphone positions relative to the direction of fire to measure the directionality of the muzzle blast. The microphones are arrayed in a half circle around the noise source as shown in the figure below. The microphone positions relative to the muzzle (firing direction (0°)) are 45°, 90°, 135° and 180°. The size of the circle is dependent on the size of the weapon being measured, i.e. the distance attenuation should prevent any measuring equipment from overloading.

The height of the microphones is 1.5 m above ground level and all microphones are located on a soft-ground surface.

The weapon under test is fired from the center of the array in the direction of the line of fire indicated below.

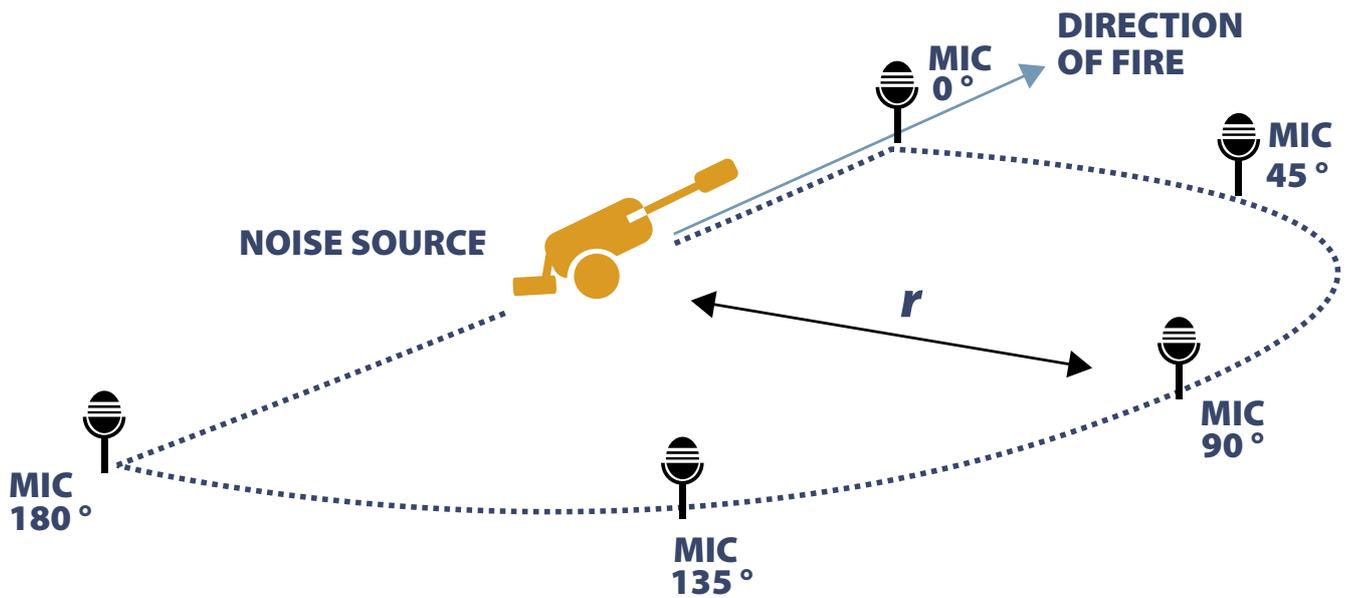


Figure 2A.1. Measurement setup when measuring the muzzle noise from heavy weapons.

Care must be taken to include only muzzle blast sound in the reported data. This is especially important for microphones situated within the mach angle for projectile generated sonic booms. Computer editing can be used to “cut” out the sonic boom from recorded data.

#### Projectile Noise

The projectile noise is normally not considered when dealing with environmental noise assessment from training and shooting areas.

#### Impact/explosion Noise

To simulate the target hitting the ground, noise from detonating HE cartridges (e.g. 81 mm HE, 120 mm HE and 155 mm HE) are measured with 3 microphones placed at different positions at a controlled space. The microphones are arrayed 120° apart around the detonation point as shown in the figure below. The size of the circle is dependent on the size of the explosion being measured.

The height of the microphones is 1.5 m above ground level and all microphones are located on a soft-ground surface.

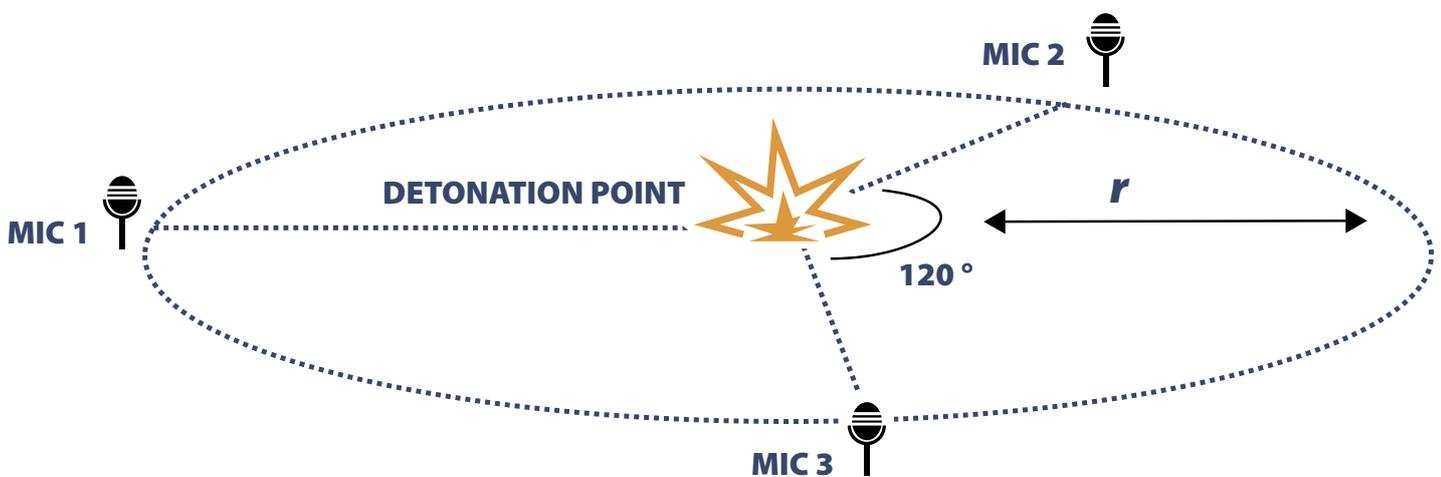


Figure 2A.2. Measurement setup when measuring the impact/explosion noise from heavy weapons.

## Terrain

Sound propagation near the ground is affected by absorption and reflection of the sound waves by the ground. Sound can either leave a source and follow a straight path to a receiver or be reflected and/or absorbed by the ground. How the sound wave reacts with the ground is influenced by the ground acoustic impedance which relates to pressure and speed.

The noise model used for environmental noise assessment accepts only free field input data. Free field, in acoustics, is a situation in which no sound reflections occur and the entire sound is received through the direct sound of a sound source. This is not the case when measuring the noise emission from heavy weapons where the surface has a huge influence on the signal picked up by the microphones.

Ground effects are accounted for by using a standard test charge of known weight of TNT (or known equivalent) detonated at a fixed height above the ground. Source data are then compared with the TNT measurements to correct for ground effects and weather related variation which would otherwise be included in the data.

It is also possible to account for ground effects using theoretical predictions. However, accurate prediction of ground effects requires knowledge of the absorptive and reflective properties (the acoustic impedance) of the surface which is difficult to obtain.

## Weather

In situations where the measurement of sound propagation over long distances is desired, the weather itself can pose a significant factor.

Static weather conditions can be accounted for by using a standard test charge of known weight of TNT as a reference source. However, due to random weather variations, the propagation of instantaneous noise events such as explosions will change over time making the sound propagation difficult to predict accurately.

To minimize the effect of meteorological conditions, measurements should not be carried out under low-level temperature inversion conditions, when wind speeds exceed levels such that the signal at the microphones becomes distorted, or when turbulent wind conditions increase background noise to unacceptable levels. The maximum permissible wind speed, measured at 2 m, shall be 6 m/s.

When the microphones are placed relatively close to the noise source, usually within 50 m, the wind direction has a

small impact on sound propagation if wind velocities are reasonably slow.

The noise model used for environmental noise assessment assumes a tailwind with a velocity of 5 m/s. This corresponds to a worst-case scenario when it comes to outdoor sound propagation.

## 3 Natural and cultural values management

### APPENDIX 3A Nature values management in different nations

#### *Finland*

Total amount of military land areas in Finland is approximately 210,000 hectares (in 2011). Also 150,000 hectares of offshore areas is in use. State enterprise Metsähallitus owns majority of the land and leases it to Defense Forces (DF) use. In Metsähallitus, the Forestry Unit governs most of the areas DF uses, but the most valuable nature areas are governed and managed by the Parks and Wildlife Unit. However, if needed, areas can be used in training and the area has no legal protection status. In this case Parks and Wildlife Unit and Defense Forces plan the use together and try to minimize the disturbance on nature.

2,693 hectares of military areas are National Protected Areas, i.e. they are protected by the Finnish Nature Conservation Act. Five Finnish National Parks include parts of military areas.

There are 80,985 hectares of Natura 2000 designated areas are within military areas. 29,304 hectares of this is land area. All areas are Special Protected Areas (SPA), i.e. taken into the Natura 2000 network by their bird values.

Forested areas are treated as normal commercially used forests. Ecological plans for the areas have been done. In these plans ecologically important areas are determined and protected at different levels. In the highest level are the most valuable nature areas. No forestry actions are allowed and areas are treated like protected areas. These include for example nature plots, plots which are strict ecological connections between two nature plots and "stepping stone" plots. All forest cuttings and management actions, like restoration, are approved by the military.

There are 16,300 hectares of ecologically protected areas in forestry areas and 8,780 hectares are of highest level of protection. The rest of the areas are forestry plots, where the forestry actions are allowed in various amount. The nature value of the plot must be saved in any case. These are usually so called "biodiversity value plots", where the

nature value can be, for example, certain species like flying squirrel (trees are left in a certain amount to allow species to move between main areas) or increasing the amount of deciduous trees. All forestry actions are negotiated between Forestry Unit and Parks and Wildlife Unit.

#### *Norway*

Total amount of military areas in Norway is approximately 1.4 million acres on land. These areas contain both owned and leased land. Norwegian armed forces is both owning and renting the areas. The Norwegian Defense Estate Agency (NDEA) is managing the areas. Many of the shooting ranges are open to public part of the time.

Only some of the heavy weapon ranges in Norway have been mapped in detail according to the characteristics of what type of surface covers the ground. It is not possible to give a complete pie chart of the vegetation types within the shooting ranges. A manual quick analysis of the norwegian shooting areas for heavy weapons shows that they consist of forest, open mountain areas and bush vegetation with pioneer plants.

Some training areas contain protected nature. In addition it occur other types of areas within the training areas where other types of restriction apply. NDEA gives advice on management and regulations for all these areas.

Forest in the military areas are managed almost like forest elsewhere in the country. The main focus is constructing a landscape that suits the user (Norwegian Defense).

#### *Denmark*

Total amount of military areas in Denmark is approximately 33,000 hectares of which approximately 27,000 is owned by the Ministry of Defense. Around 6,000 hectares are rented from different owners. The largest shooting and training range in Denmark is around 6400 hectares. The military areas are dispersed throughout the country with around 40 shooting or training ranges in total.

More than half of the military areas are designated Natura 2000 areas either as Special Protected Areas (bird values) or Habitat areas (other species and nature types) or both. Furthermore, more than half of the areas are protected by national law, which means, that these areas can be used continuously for military purposes, but it is not allowed to use the areas in a way that reduce the nature values.

The military areas are managed by the Danish Defense Estates and Infrastructure Organization, which makes management plans for all the larger shooting or training ranges. There is a clear priority in the management of the areas: first priority is to keep the areas suitable for training and

education of soldiers. Second priority is biodiversity and third priority is recreational use for the public.

In general, the military areas are open for the public if there are no military activities and no security risks.

Approximately 17 % of the military areas in Denmark are covered by forest. Forested areas are managed in the same way as the areas in general, which means that training and education of soldiers is the most important purpose and biodiversity is second. The military forests are often located on low-productive soil due to historical reasons. Around 35% of the forest is coniferous and the rest is deciduous. A large part of the forests are designated to be virgin forests in the future.

#### *Sweden*

All land used for military training, shooting and testing is owned and managed by the Swedish Fortifications Agency, SFA. The total area is 370,000 hectares (2016). Half of it consists of forest, another 40 per cent is peat land and the rest is mostly grazing land besides bedrock, agricultural and other areas.

The forest is managed with low intensity compared to normal Swedish forestry, mainly due to nature conservation restrictions and limited access due to military activities. The forestry is not certified but treatment is made according to the FSC criteria. The open land used for training and shooting is burned or mowed except for areas where grazing is organized by tenants. Some cereal production is carried out in areas that more or less have buffer zone characteristics.

162,000 hectares are protected as Natura 2000 and 151,000 hectares as nature conservation areas. These are administrated by the county governments with the Environmental Protection Agency, EPA, as the overall coordinating authority. An agreement between SFA and EPA was made in 2010 to protect another 32,400 hectares consisting of forested areas with especially pristine values. The mentioned areas are overlapping but all in all, more than half of the area owned by SFA is protected.

#### *United States Army Europe - Germany*

The issues of sovereignty arising from the use of land in Germany by the United States is accommodated by two principle initiatives; the Status of Forces Agreements (SOFA) in the North Atlantic Treaty Organization (NATO) – a Ministerial level agreement between the governments of the United States and Germany, and the Final Governing Standards – Germany (FGS-G) that intend to combine two national regulatory regimes at a more operational level. The unifying approach of the FGS-G has evolved from Presidential

Executive Orders (E.O.) – notably in 1973 E.O. 11752 (1-801) ‘Federal facilities [military installations] outside the United States shall ensure that such construction or operation complies with the environmental protection control standards of general applicability in the host country or jurisdiction’.

At JMRC Hohenfels approximately 58% of the training area consists of forested vegetation communities, a significant increase of 8% over the last 20 years. The main types of existing forests include pine (*Pinus sylvestris*), beech (*Fagus sylvatica*), and spruce (*Picea abies*) in multiple variations. The spruce forests are not native and are subsequently being phased out by the Bundesforst by thinning and inter-planting. Some of the more ecological valuable forested communities are dominated by mature beech (*Fagus sylvatica*). They are quite rare and regularly confined to the hilltops dominated by stony soils with very low nutrient and water supply. There are many other areas of ecological importance, for example: pine woodlands covering semi-dry turfs, thermophilic beech covers with orchids in the ground layer, or oak-rich (*Quercus spec.*) stands mixed with wild service berry (*Sorbus torminalis*) and endemic species of the whitebeam (*Sorbus arla agg.*).

Ninety two percent (92%) of the JMRC Hohenfels training is a nominated Natura 2000 area. The primary Natura 2000 habitat types found at JMRC Hohenfels is the dry nutrient poor meadow (6210) and the most significant threat to the preservation of this type of vegetation community is overgrowth of woody shrubs or tree species. By preserving the open maneuver land in the JMRC Hohenfels, the natural resource management benefit is the ultimate preservation of one of the rarest habitats listed in the EU Natura 2000 Directives.

The German Federal Forestry Office Hohenfels is responsible for the management of all forests, as well as non-forested areas, wildlife and Natura 2000 implementation. This responsibility is authorized according to § 2 of the Institute for Federal Real Estate Act (*BImA-G / Gesetz über die Bundesanstalt für Immobilienaufgaben*). The Supplementary Agreement (Article 53) to the NATO SOFA defines that within an accommodation made available to the US Forces for its exclusive use, a force or civilian component may take all the measures necessary for the satisfactory fulfillment of its defense responsibilities. The US Forces have the right to do everything necessary to safeguard their military interests as long as these actions are IAW German law. U.S. Army Europe has since based its protocol and management policies on these landmark decisions which ensure the support of BImA and the German Federal Forestry Office and makes military training the overriding priority in all matters

dealing with training area operations and management of training area resources.

The two major US Army training areas in Germany are Grafenwoehr Training Area and the Joint Multinational Readiness Center (JMRC) in Hohenfels. Grafenwoehr Training Area is the primary live fire range complex for US Army Europe, and it encompasses 230 square kilometers, or 22,892 ha. Of this area, 19,279 ha or 84% is Natura 2000 (FFH+SPA). JMRC Hohenfels is the US Army’s Combat Training Center (CTC) in Europe. JMRC Hohenfels is 160 square kilometers, or 14,900 ha, with 92% falling under Natura 2000.

### APPENDIX 3B Cultural values regulation

As it can be noted from table 1, presence of culturally valuable artifacts, sites and practices are found across all the participating nations. This underlines the importance of taking this issue into consideration, when making area management or activity plans and when carrying out activities.

#### Cultural heritage examples

An example of cultural heritage on military land in Denmark is barrows from the bronze age. The barrows were typically formed as round domes of 5-15 meters height with a diameter of 15-50 meters. With time the barrows have eroded and now they are typically no more than 5 meters high. The erosion may make identification of the barrows more challenging under certain conditions for training personnel (e.g. in unfamiliar terrains or in reduced visibility). In farm lands most of the barrows have been erased to make the land arable. Similarly, dykes from earlier traditional farming have been erased to make small fields bigger, while these are in a larger extent preserved on military training grounds. In Finland exist old hunting and tar pits in many dry shooting areas, which are protected under the legislation.

#### Legislation examples

In Denmark there is no general exemption for military activities or projects supporting military activities in relation to legislation on protection of cultural heritage. It is not allowed to change the conditions of dykes, barrows or other historical artifacts in Denmark. Unregistered cultural heritage areas and artifacts are also protected. If you find something during military training like historical artifacts, stones in a clear pattern, postholes (circular dark soil spots in a pattern), you are obliged to stop the activity (whether it is digging or explosions) that exposed the find and contact the local military office, which will contact the local historic museum. In addition, an area may be protected through “Fredning”, where each site protection acts as an individual law with own requirements and prescriptions.

**Table 3B.1: Relevant cultural heritage issues on heavy weapon training ranges**

<i>Cultural heritage on training ranges with heavy weapons</i>	Denmark	Finland	Germany	Norway	Sweden
Presence of historical artifacts	Y	Y	Y	Y	Y
Presence of historical sites	Y	Y	Y	Y	Y
Presence of religious or traditional land use	N	Y	Y	Y	Y
Presence of recreational use	Y	Y	Y	Y	Y

Table 1: Explanation:

Y = Yes (in table above: This issue is relevant for this nation)

N = No (in table above: This issue is not relevant for this nation)

? = Not investigated

In Norway, all cultural heritage (e.g. artifacts and monuments) that originates from before 1537 is automatically protected and often called “the invisible cultural heritage”. In daily work with cultural heritage examples of artifacts is ranging from hunting equipment and settlements and all the way to bronze age, iron age and Viking era. Included in the same protected category is cultural heritage from Lapland culture older than 100 years. All cultural heritage from the period after 1537 and up to today is categorized “recent time”, by archaeologists.

Cultural heritage from recent time (after 1537) is regulated through Planning and building act (last revised September 2015). This kind of cultural heritage can for example be minor traces in the terrain (a fireplace, remains of buildings).

#### **US Army, Germany**

In the Federal Republic of Germany, the duties and rights of owners of cultural monuments are regulated by the state preservation acts (Landesdenkmalschutzgesetzen) of the individual federal states (Bundesländer), since the responsibility for the cultural and educational policy rests with the individual states. For exercising the functions of protection and preservation of monuments under the Bavarian State Historic Preservation Act, the Lower Monument Authority (UDB - Untere Denkmalbehörde) performs all acts of state and the State Authority for the Protection of Cultural

Resources (BLfD - Landesamt für Denkmalpflege) performs all scientific tasks. Therefore, it is necessary to distinguish carefully between protection and preservation of cultural resources.

#### **Implementation examples**

In Denmark the protection of visible historical monuments and protected sites are taken into consideration when making management plans for each terrain and general instructions for military activities. Protection of cultural heritage is also taken into consideration, when defined projects (e.g. construction of a specific shooting range) are established in the terrain. There are no common, written instructions to military users of terrain on protection of cultural heritage. These kinds of instructions have traditionally been the responsibility of local management on each terrain in relation to specific activities. The Danish archeological regulators have underlined the importance of incorporating the following protective measures in relation to heavy weapon use:

- No activities in a 2 m zone around visible artifacts (as barrows)
- Fire on burial mounds should be prevented and burning must not happen intentionally.
- A screening of presence of protected sites incorporated in the planning phase of all military activities.

In Sweden soldiers get a general basic training on how to prevent damages during exercises. This is also described in the Environmental handbook. Preceding all (major) exercises, an Environmental annex is derived where maps of restrictions, how to prevent damages, how to report incidents and so on are described. The protection of cultural artifacts is included as a part of these overall environmental precautions.

In Norway each range is required to have a land-use plan. During planning of military training which includes artillery and live ammunition it will be both possible and required to check to find out whether or not this activity is according

to the land-use plan. In the land-use plan all known automatically protected cultural heritage will have been taken into account. In Norway the Directorate for Cultural Heritage have published a network based map showing the location of known cultural heritage (Askeladden). Evolvement and updating of the map is based on the consecutively development of land-use plans and development measures. Several military training areas were established before it became mandatory to include cultural heritage in land-use management documents. Therefore several of the ranges is wrongly presented to have no cultural heritage.

**Table 3B.2: Protection and implementation of protection of cultural values on Heavy Weapon ranges**

<i>Practices</i>	<b>Denmark</b>	<b>Finland</b>	<b>Germany</b>	<b>Norway</b>	<b>Sweden</b>
<b>Protection of visible artifacts/monuments</b>	Y	Y	Y	Y	Y
<b>Protection zones around artifacts</b>	Y	?	Y	?	Y
<b>Military exemptions</b>	N	N	?	N	N
<b>Visibility of monument, requirements</b>	Y	?	Y	?	Y
<b>International protection (e.g. UNESCO)</b>	N	N	Y	?	N
<b>Protection of invisible artifacts</b>	Y	?	?	Y	Y
<b>Designated instructions to military personnel</b>	N	?	Y	?	Y
<b>Designated instructions to management personnel</b>	N	?	Y	Y	Y
<b>Protected traditional or religious practices associated to areas within military training grounds</b>	N	Y	?	?	Y
<b>Protection of recreational use of military training grounds</b>	Y	N	?	?	N

Explanation:

Y = Yes (in table above: This is present in this nation)

N = No (in table above: This is not present in this nation)

? = Not investigated

At US Army installations in Europe, cultural resources are managed under the Directorate of Public Works (DPW) Environmental Office, in accordance with the above legislation. In collaboration with the Integrated Training Area Management (ITAM) programs, the DPW Environmental Offices provide information to Soldiers to build awareness of cultural resources on installations. This includes procedures to avoid or minimize impacts to cultural resources.

As it can be seen from Table 2, there is a wide legal protection of cultural artifacts and sites across the nations at terrains with heavy weapon ranges. The protection can be strictly in regard to preservation but may also extend to accessibility e.g. through visibility. Most of the participating nations have in a higher degree centralized and formalized instructions and proliferation of information in regard to protection of cultural heritage on military terrains. This can act as an efficient way to engage with the prevailing legal protection.

## APPENDIX 3C Risk Identification

### Example of Risk Identification

Only nature values that are protected by law are evaluated in this risk identification. The example is not based upon an actual case, but it contains typical heavy weapons activities and typical nature and cultural heritage values. The purpose of this tool is to provide an example to identify military activities and evaluate their impacts and risks to the nature and cultural values. All the ranges are different and the tool has to be modified accordingly for range activities and nature values. The impact analysis has to be made in cooperation with range management and environmental experts.

Below is a description of the military activities and nature values for this example. A visual reference and the Risk Identification Chart for this example scenario can be found in following pages in Figures 3C.1 and in Tables 3C.1 and 3C.2.

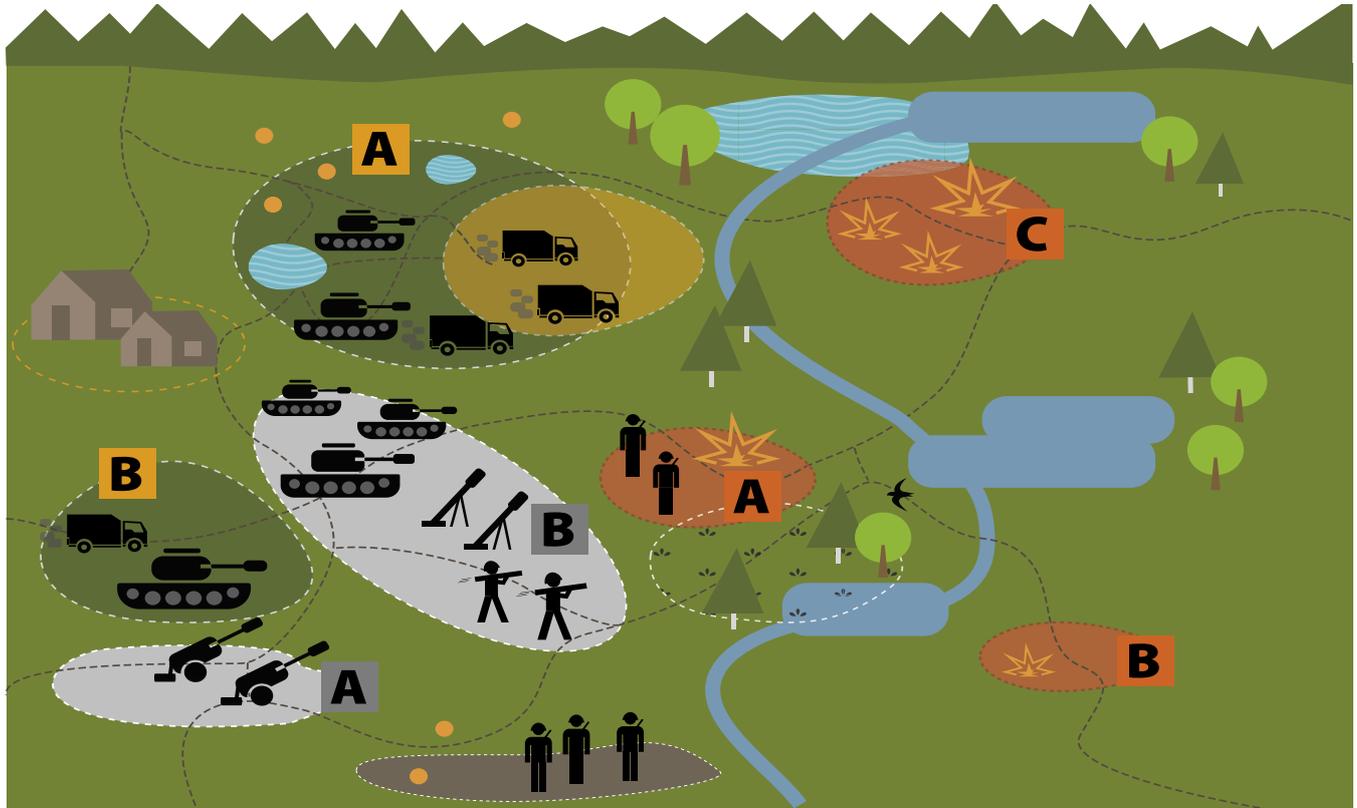
### Description of the military activities

In this heavy weapons range there is weekly training activity year around; conducted mostly during daytime, but also during evenings and nights. Weather condition is a typical Nordic climate with seasonal changes. In the wintertime there is normally at least short periods of snow cover and the water systems are ice covered. In this range the following weapon systems are allowed for training: mortar, tank, artillery, antitank, rifle and other pioneer explosives. There are also dedicated areas for heavy maneuver training, accommodation and maintenance activities.

### Description of nature values

In the range there are several protected areas for nature values and cultural heritage. For example, there is an old forest where forestry is not allowed. In the forest there are nesting protected bird species that are sensitive to noise and presence of people. Protected heath habitat has been formed because of military activity. The habitat is sensitive to erosion and there is also a risk of vegetation overgrowing and invasive species. Protected insects like spiders and butterflies are dependent on the heath habitat. Protected wetland habitat with protected frog species is part of the local surface water system.

In the range there are many historical artifacts like structures, cave paintings and graves. The artifacts can be located but have not been marked properly in the area.



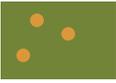
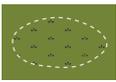
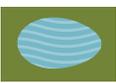
**Military activity symbols**

	<b>Firing area</b> A = Artillery B = Tanks, mortar, antitank
	<b>Impact area</b> A = Rifle range B = Antitank C = Artillery, tank, mortar
	<b>Maneuvering area</b> A = Heavy vehicles off road B = Heavy vehicles maintenance, gas station
	<b>Accommodation area</b>

**Other symbols**

	<b>Road or track</b>
	<b>Surface water</b> Lake or pond River or stream

**Nature and cultural value symbols**

	<b>Cultural heritage</b> Historical artifacts
	<b>Protected area</b> Forest and protected birds Heat Habitat and protected insects
	<b>Digging and construction area</b>
	<b>Protected area</b> Wetland and protected amphibians

	Garrison, repair shop, depot, etc...
	Explosions, OD, HW Impact area
	Antitank rockets shooting range
	Tanks, armoured heavy vehicles
	Artillery, HW Firing point
	Mortar, HW Firing point
	Military personnel
	Trucks, heavy vehicles
	Nature, ecological values

**Figure 3C.1. Heavy Weapon Range Map, Military Activities and Nature Values**

**Table 3C.1. Nature values Risk Identification Chart**

	Noise and vibration	Dust / Air emission	Presence of people	Contaminants: explosives, heavy metals	Physical impacts: soil and vegetation, cultural values	Physical impacts: water system	Protected values that are impacted
Firing area A: Artillery	-	0		0	0	0	Protected value: Birds
Firing area B: Tank, mortar, antitank	--	0	-	0	0	0	Protected value: Birds
Impact area A: Rifle range, pioneers	--	0	-	-	- / +	0	Protected value: Forest habitat and birds
Impact area B: Antitank	-	0	0	0	0	0	Protected value: Birds
Impact area C: Artillery	-	0	0	-	0	---	Protected value: Wetland habitat and amphibians
Maneuvering area A: Heavy vehicles, off road		-	0	-		-- / ++	Protected value: Cultural heritage, wetland habitat and amphibians
Maneuvering area B: Heavy vehicles maintenance, gas station	0	0	0	0	0	0	
Accommodation area	0	0	0	0	0	0	
Digging and construction area	0	0	0	0	--	0	Protected value: cultural heritage

+++ high positive impact  
 ++ moderate positive impact  
 + small positive impact  
 0 no impact  
 --- high negative impact  
 -- moderate negative impact  
 - small negative impact

- / 0	Monitoring, no immediate mitigation actions
--	Consider mitigation actions
---	Mitigation or compensation action needed

**Table 3C.1. Possible impacts on the nature values and mitigation or compensation actions**

	Negative impacts	Positive impacts	Mitigation or compensation actions
<b>Protected area: Forest and protected birds</b>	Noise from firing areas (A, B) and impact areas (A, B, C) and presence of people in firing area B and Impact area A can disturb protected birds especially during the nesting period.	Forest is a natural noise preventing "structure" especially for small caliber weapons shooting noise.	Seasonal timing of presence of people and heavy weapons shooting. Less activities during the nesting period.
	Explosions in the impact area A (inside the protected forest) can cause small destruction of the habitat.	Impact area A explosions and fires can have positive effects to the habitat (dead and burned wood).	Controlled explosion of trees (by pioneers) increase biodiversity and increase the amount of dead wood in the habitat.
<b>Protected area: Wetland and protected amphibians</b>	Explosions in the impact area C (inside the protected wetland) destroys the habitat and kills protected amphibians.		Relocation the impact area outside of the protected habitat. Compensate the value to somewhere else.
	Contaminants (explosives) from the impact area C to the protected wetland can cause small disturbance to the protected amphibians.	Wetland can be used as a water reservoir in case of fire.	
<b>Protected area: Heat habitat and insects</b>	Very intensive off-road driving with heavy vehicles can cause erosion and destruction of the habitat. Too low level of off-road driving doesn't prevent overgrowth of the habitat.	Certain level of off-road driving can keep the area open (necessary for the habitat).	Controlled off-road driving if the activity is too intensive (marked routes). Controlled burning or other methods can also be used to keep area open.
<b>Protected area: Cultural heritage (historical artifacts)</b>	Activities inside the Maneuvering area A and Digging and construction area can destroy historical artifacts.		Clear marking and fencing of the historical artifacts.

The above is a recommended process for identifying risks from a military training area scenario. Using the above training area example, the above matrix was produced to identify the risks and magnitude (high, moderate or low, negative or positive) of impact to protected cultural and nature values.

After completing the matrix, the table above can further process the information into the impacted protected areas and potential negative and positive impacts. Finally, from this information a determination can be made on required mitigation measures.

## APPENDIX 3D, Risk assessment of cultural heritage values

### Risk assessment of cultural heritage values

This appendix elaborates how to assess risk of cultural heritage values including how to reduce risks of damaging cultural heritage values.

#### Artifacts

Cultural artifacts can be of a highly diverse nature and can fall under different legal protection regimes. Even their potential presence and importance can vary across nations and sites. Therefore, to prevent significant damage the first step should be to conduct an analysis.

#### What is the likelihood of presence of cultural significant artifacts on the terrain?

- If insignificant: Contingency plans for accidental discovery can become of use.
- If significant: What geographical information is available? What registrations on known artifacts can be compiled? What is the likelihood of unregistered or unmapped artifacts? In relation to larger scaled projects, a historical analysis for areas can be considered e.g. of impact areas or areas with a high fire hazard. A contingency plan for accidental discoveries and accidental damages will most likely be necessary. Is in-situ protection in place for the type of activities carried out on the terrain?

#### Depending on the results of this analysis, the following could be considered in the specific activity planning phase and implementation:

- Are there proper maps of already registered cultural artifacts? Do they include cautionary information (like safety zones) or only of physical presence? What instructions are given together with the map information? Are the maps easily applicable for the terrain (e.g. is it easily identifiable from the map, where an underground artifact may be present)?
- Are instructions (e.g. no activity within areas demarcated by white poles) given to all relevant personnel and in a form that can be properly understood and used in the terrain?
- Is the contingency plan formulated and communicated to the relevant personnel? Does the contingency plan include all relevant information in regard to chain of events for the person it is given to (e.g. POC, what to react on, timing, actions in the field at sighting (registration, demarcation, full/partly stop of activity))? Is a proper registration for future use made when an accidental find is made?

- Is there an exemption/permission process in place? If an activity can damage an artifact or in other way be in conflict with laws relating to cultural heritage, can an alternative location for the activity be found? If not, can the activity be modified in an insignificant or positive way for military purposes? If not, is it possible and/or feasible to move the artifact or make protecting infrastructure that allows for the military activity? If not, can it be legally accepted, that the military activity is prioritized instead of the protection of that particular artifact?
- Is there proper in-situ protection in place?

#### Cultural practices

An analysis of cultural practices can be used as a template for ways to decrease risks of conflicts between military activities on heavy weapon ranges and civilian use of military terrains (e.g. hunting, grazing, religious, traditional, unorganized recreational).

#### What is the likelihood of presence of cultural practices on the terrain?

- If the likelihood is small: Is this ensured (through e.g. proper fencing) and is a contingency plan needed?
- If the likelihood is significant, a stakeholder analysis and identification can be used as basis for:
  - Contracts or clarity about rights
  - Mapping and monitoring, if necessary (identification of relevant areas)
  - Establishing POC and agreement about coordination
  - Contingency plans (for military, land owners and civilian users)
  - Consideration of physical access (fences, guards, roads) and location of facilities (benches, open fishing spots, fitness equipment)
  - Communication of instructions for recreational use of terrains (when, how, where, warnings, POC)
    - ◆ Signs (consider placements)
    - ◆ Folders
    - ◆ Maps for recreational use (with facilities and roads and closed areas)
  - Stakeholder dialog (e.g. with local community, public participation projects, community involvement, agreements with defined groups)
  - Legal actions

## APPENDIX 3E – Managing open areas

### The process of keeping the areas open

#### Investigate overgrowth species

First you have to investigate the process of overgrowth and identify the plant species prone to fast overgrowth. The species will differ between nature types. A list of target species for managing open areas will be derived from these investigations.

#### Make a management plan

In order to target the right species, a management plan should be made for the area which is meant to be kept open. The management plan has several advantages: It provides time and cost savings but also continuity in a case of personnel changes. Management plan must be regularly updated, especially due to natural succession.

The most important measures in managing open areas are cutting of tall forest, cutting of woody bushes, mowing or allowing grazing animals in the area. Also using chemicals or controlled burning can be used in some cases. The regulations on use of chemicals to erase vegetation are harmonized within European Union

#### Keep records of which species you fight

You will continuously have to keep track of the succession stages in your area to make the right decisions about when,

where and how the areas are being kept open. If an already open area is on its way to get overgrown, special measures have to be taken according to the management plan.

- a. In very early stages of natural succession the main action is to keep the grass low. In this stage you can use lawn movers or grazing animals (goats or sheep).
- b. In the next stage the deciduous forest species are growing fast. At this stage you will need more sturdy equipment, like a flail mower. Some grazing animals are also able to fight shrubs and trim trees just as well as human work.

It is important to include enough time and effort to fight overgrowth in the annual plans. The process has a tendency to take more time than estimated.

**APPENDIX 3F Communication**

The diagram below describes a seven step process for outreach. This is based on work by the US-South Africa Environmental Security Working Group, *Outreach for*

*Mission Sustainability: Working to Balance Military and Civilian Community Needs.*



**Figure 3F.1. Process for creating an outreach program**

## 4 Contaminant management

### Appendix 4A Typical contaminant emissions for different weapons systems

Munitions Residues Deposition Data										Compiled 30 JAN 2006 by MRW Updated 29 DEC 2015 (MEW & MRW)			
Note: Classified Canadian data removed.										Measured Deposition Area (m <sup>2</sup> )	Consumption Efficiency	Residues / Round (mg)	Publication / Notes
Weapon System	Weapon Size	Number Tested	Plumes Sampled	Energetic Material	Energetic Compound	Residues / Round (mg)	Consumption Efficiency	Measured Deposition Area (m <sup>2</sup> )	Publication / Notes				
<b>Live-fire detonations Mortars</b>	60-mm	7	7	Comp B	RDX / HMX	0,073	99,99997%	210	Energ Matl & Chem Prop (2011)10(2) ERDC/CRREL TR-06-10				
		5	5	Comp B <sup>(e)</sup>	RDX / HMX	0,074	99,99997%	23	Chemosphere (2005) 61: 888-894 ERDC/CRREL TR-03-16				
		7	7	PAX-21 <sup>(a)</sup>	RDX / HMX DNAN AP**	9,2 7,1 14 000	99,9929% 99,9941% 85 % 96 %	330	PEP (2013) 38: 399-409 JHM 262(2013) 228-233 (Overall Eff.)				
		7	7	IMX-104 <sup>(a)</sup>	RDX/HMX DNAN NTO	4,5 5,3 2 200	99,994% 99,995% 98,8%	580	PEP (2014) 39:243-250 (Overall Eff.)				
		14	14	Comp B	RDX / HMX	8,5	99,9986%	230	Energ Matl & Chem Prop (2011)10(2) ERDC/CRREL TR-03-16				
		3	3	Comp B	RDX / HMX	10	99,9983%		Energ Matl & Chem Prop (2011)10(2) ERDC/CRREL TR-11-13 (Ch. 6)				
	81-mm	7	7	IMX-104 <sup>(a)</sup>	RDX/HMX DNAN NTO	16 27 1 900	99,989% 99,990% 99,56 % 99,77 %	610	PEP (2014) 39:243-250 (Overall Eff.)				
		5	5	IMX-104 <sup>(a)</sup>	RDX/HMX DNAN NTO	7,6 7,8 540	99,995% 99,997% 99,87 % 99,93 %	670	ERDC/CRREL TR-15-3 (Overall Eff.)				
		2	1	IMX-104 <sup>(a,b)</sup>	RDX/HMX DNAN NTO	3,8 13 1 150	99,998% 99,995% 99,73 % 99,86 %	620	SERDP 2015 Interim Progress Report (Overall Eff.)				



Tank	120-mm (Breaching)				PAX-48 <sup>(a)</sup>	RDX/HMX DNAN NTO	-ND- -ND- Classified	>99,998% >99,998% 99,998%	1400	SERDP 2015 Interim Progress Report
<b>Rockets</b>	227-mm	6	1	PETN-109	RDX	-ND-	—	—	—	Energy Matl & Chem Prop (2011)10(2)
<b>Hand Grenades</b>	—	7	7	Comp B	RDX	0,025	99,99999%	35	35	ERDC/CRREL TR-03-16
<b>Rifle Grenade</b>	40-mm	3	3	Comp B	RDX	1,6	99,99 %	5	5	"
<b>Mines</b>	—	8	8	C4	RDX	16,0	99,997%	160	160	"
<b>Blow-in-place detonations</b>										
<b>Mortars</b>	60-mm	7	7	Comp B + C4	RDX / HMX	200	99,97 %	500	500	Energy Matl & Chem Prop (2011)10(2)
		7	7	PAX-21+ C4	RDX / HMX	860	99,87 %	330	330	ERDC/CRREL TR-08-19
					DNAN	740	99,38 %			PEP (2013) 38: 399-409
					AP**	35 000	62 %			J. Haz. Matl 262(2013) 228-233
							96 %			(Overall Eff.)
		7	7	IMX-104 + C4	RDX/HMX	8 300	98,62 %	580	580	PEP (2014) 39:243-250
					DNAN	20 120	81,7%			
					NTO	89 000	51 %			(Overall Eff.)
							87 %			
	81-mm	7	7	Comp B + C4	RDX / HMX	150	99,986%	820	820	Energy Matl & Chem Prop (2011)10(2)
		7	7	IMX-104 + C4	RDX/HMX	20 000	97,1%	590	590	ERDC/CRREL TR-05-8
					DNAN	45 000	83 %			PEP (2014) 39:243-250
					NTO	230 000	47 %			(Overall Eff.)
							78 %			
		7	7	IMX-104 + C4	RDX/HMX	2 100	99,69 %	820	820	SERDP 2015 Interim Progress Report
					DNAN	5 000	98,1%			
					NTO	45 000	90 %			(Overall Eff.)
							96 %			
	120-mm	7	7	Comp B + C4	RDX / HMX	25	99,999%	1500	1500	Energy Matl & Chem Prop (2011)10(2)
										ERDC/CRREL TR-08-19
										<b>Average: BIP Mortars (HE)</b>
										<b>Average: BIP Mortars (IHE)</b>
										93 %





	204-mm	1	1	AR 360B	AP	<1.6	> 99,99999%	—	PEP (2012) 37:393-406 ERDC TR-08-1
<b>Small Cal.</b>	204-mm	18	2	AR 360B	AP	ND	—	80	PEP (2012) 37:393-406
	9-mm Pistol	100	1	WPR289	NG	2,1	94,68 %	16	PEP (2012) 37:393-406
	5.56-mm Rifle	100	1	WC844	NG	1,8	98,90 %	70	ERDC/CRREL TR-07-17
	5.56-mm MG	200	1	WC844	NG	1,3	99,29 %	110	"
	7.62-mm MG	100	1	WC846	NG	1,5	99,4%	94	"
	12.7-mm MG	195	2	WC860 / 857	DNT	0,0018	99,95 %	310	"
					NG	11	99,3%		"
<b>Medium Cal.</b>	40-mm	127	1	F15080	NG	2,2	99,4%	79	PEP (2012) 37:393-406
		144	1	M2	NG	76	91,6%	64	ERDC/CRREL TR-10-10
									"
<b>Burn points</b>	81-mm	10	1	M9	NG	84	98,4%	0	J Haz Mat (2010) 173:115-122
<b>Mortar -Snow</b>	120-mm	11	1	M45	NG	2 273	82,5%		ERDC/CRREL TR-06-10
									J Haz Mat (2010) 173:115-122
<b>Mortar-Frozen ground</b>	120-mm	11	1	M45	NG	664	94,9%	0	ERDC/CRREL TR-09-8
<b>Mortar-Pan</b>	120-mm	10	1	M45	NG	27	99,8%	10	"
									"
<b>Howitzer-Dry sand</b>	105-mm	10	1	M1: 5 Chrg 6 & 5 Chrg 7	DNT	620	99,0%	0,5	"
<b>Howitzer-Wet sand</b>	105-mm	10	1	M1: 5 Chrg 6 & 5 Chrg 7	DNT	650	99,0%	0,5	"
									"
<b>Howitzer-Dry sand</b>	155-mm	6	2	Charge 4	NG	3	99,998%	0,5	ERDC/CRREL TR-11-13
					NQ	33	99,99 %		DRDC Valcartier TR 2010-269
<b>Howitzer-Dry sand</b>	155-mm	4	2	Charge 7	NG	2,0	99,999%	0,5	"
					NQ	16	99,998%		"

<b>Burn pans</b>												
<b>CRREL Mk-1</b>	Full-size Pan (1-x2-m)	3 burns	1	M1: Mixed (276 kg)	DNT	2300***	99,992%	150	J Haz Mat 219-220(2012): 89-94			
<b>CRREL Mk-2</b>	Full-size Pan (1-x2-m)	1 burn	1	M1: Chg 6&7 (65 kg)	DNT	1600***	99,98 %	150	J Haz Mat 219-220(2012): 89-94			
<b>CRREL Mk-3</b>	Full-size Pan (1-x2-m)	1 burn <sup>(d)</sup>	1	M1: Chg 6&7 (90 kg)	DNT	NDD***	>99,999%	150	CRREL Test Report (Jun 2013)			
<b>CRREL Mk-3a</b>	Mortar Unit Pan (1x1.2 m)	1 burn <sup>(d)</sup>	1	Mixed mortar (16 kg)	NG	NDD***	>99,999%	150	CRREL Test Report (Jun 2014)			
<b>CRREL Mk-4</b>	Full-size Pan (1-x2-m)	5 burns <sup>(d)</sup>	1	M1: Chg 6&7 (90 kg max) (458 kg Total)	DNT	NDD***	>99,999%	150	CRREL Test Report (Dec 2015)			
<b>Notes:</b>	<p>(a) Command detonated                      (b) Co-located detonations                      (c) Whole population sample from swept ice                      (d) Residues in pan also analyzed. See respective test reports.                      (e) Proximity fuze set at 2-m detonation elevation                      *The energetics mass per round for the 105-mm burn point tests is the combined total of a charge 6 and charge 7 bag                      **For AP, the percent levels are reported for perchlorate (91 g ClO<sub>4</sub>)                      *** Estimated total mass outside pan measured on snow (Mk-1 and Mk-2) or derived from pre- and post-burn soil concentrations</p> <p>ND = No analyte detected in samples (below detection limits).                      NDD=No detectable difference above baseline measurement</p>											

## Appendix 4B Guidance for using the RID traffic light rating system for indicating risk potential

The table below provide supportive information for the qualitative risk assessment procedure described in chapter 20 and interpretation of the results of the assessment.

### RID: TRAFFIC LIGHT -RATING. SUPPORTIVE TABLES FOR TRANSPORT AND/OR EXPOSURE IDENTIFICATION

Soil medium affects on	Gravel			Sand			Silt			Clay			Peat			Bedrock		
Direct contact to soil	●				●	●			●		●			●		●		
Accumulation on soil	●				●			●	●			●			●	●		
Vertical transport (from surface soil to groundwater)			●			●		●		●			●	●		●		
Horizontal transport (Surface water runoff)		●	●				●				●		●	●				●

Groundwater	
Classified groundwater area with or without water usage	●
Groundwater hydraulically connected to classified nature areas	●
Non-classified groundwater area	●
Site is not on groundwater area	●

Surface water	
Directly connected to surface water	●
Indirectly connected to surface water	●
Site is not connected to surface water	●

Nature values	
Classified nature areas, endangered species habitats	●
Decision unit connected to classified nature area	●
Site has no significant nature values	●

Corrective Action	
Additional investigations, Quantitative risk assessment, EIA, Risk management, Mitigation...	●
Defined monitoring, Additional investigations, Risk assessments	●
BAT-management, Monitoring...	●

**Table 4B.1. Supportive tables for the RID**

## Appendix 4C Physicochemical properties of the most common contaminants of concern on military ranges

Substance:	TNT	RDX	HMX	2,4-DNT	2,6-DNT	TNB	2-AT	4-AT	NG	PETN	DFA	EC	AP
CAS:	118-96-7 227,13	121-82-4 222,12	2691-41-0 296,2	121-14-2 182,15	606-20-2 182,15	99-35-4 213,1	35572-78-2 197,15	19406-51-0 197,15	55-63-0 227,085	78-11-5 316,14	122-39-4 169,23	85-98-3 268,36	7790-98-9 117,49
Molecular weight	g/mol												
Water solubility, S	mg/l								1250				2,49E+05
highly soluble	>1000												
soluble	100 - 1000	200		300	206	385	42	42			300		
moderately soluble	10 - 100	56,3								91,41		80	
poorly soluble	0,1 - 10		5										
very poorly soluble	< 0,1												
Vapor pressure, Vpa	Pa (20 - 25 C)												
highly volatile	> 100												
volatile	1 - 100												
moderately volatile	0,01 - 1			2,00E-02	8,00E-02		5,00E-03	3,00E-03	2,67E-02		0,13	8,60E-04	
poorly volatile	0,0001 - 0,01	3,00E-04											
very poorly volatile	< 0,0001	5,33E-07	4,00E-12			6,50E-13				7,17E-07			
Henry's Law constant, H	atm m <sup>3</sup> /mol												
highly volatile	> 0,001												
volatile	10 <sup>-5</sup> - 10 <sup>-3</sup>												
poorly volatile	10 <sup>-7</sup> - 10 <sup>-5</sup>	4,57E-07		1,86E-07	7,47E-07				3,40E-06		3,39E-06		
very poorly volatile	< 10 <sup>-7</sup>	1,96E-11	2,60E-15			3,08E-09	6,62E-09	6,62E-09		1,70E-09		8,22E-08	
Organic carbon partition coefficient (mobility)	K <sub>oc</sub>												
very mobile	< 50										2,54		
mobile	50 - 150			95,5	69,2	75,86	100,5	100,5	130,8				
moderately mobile	150 - 500	177											
poorly mobile	500 - 2000	195,4	676							757,6			
very poorly mobile	> 2000												
Octanol/water partitioning coefficient (accumulation)	logK <sub>ow</sub>												
very accumulative	> 5												
accumulative	> 4												
slightly accumulative	> 3			1,99	2,02	1,18	1,94	1,91	1,62	3,7	3,5	3,4	
not accumulative	< 3	2,2	0,9	0,17									

Appendix 4D Sites of special concern and suggested risk management options

Site	Characteristics		Contaminant Management Options		Cost Estimate	Comments
	Some characterization of contaminant migration potential to be added!	In order of preference, and arguments for ranking	Design	Use and Maintenance		
Ranked according to potential risk, based on past surveys and observations					Use € - €€€€ for relative cost	
Demolition range / Explosive ordnance disposal range	Small-medium sized well-defined area with energetics/metals from detonations. Pollutant (EW, metals) mainly in the disturbed topsoil (tens of cm to 3 m).	Walls, berms and pits for noise control	Maintenance, EOD and cleaning on regular bases. Monitoring Periodical soil investigations Propellant burning trays Periodical contaminated soil removal	€ € € € €€	Replace C <sub>4</sub> (RDX) OB/OD not recommended in GW-areas OB only at burning trays	
Anti-tank rockets/Recoilless rifles firing point	Small well defined area with pollutant from the propellant in the backblast area and plume in front of position. Pollutant (ropellants) solely in the topmost centimetres.	Impermeable structure and surface water control at the back-blast area Non-vegetated (gravel bed) back-blast area	Maintenance and cleaning Monitoring Periodical soil investigations IR-heater treatment for top soil Periodical contaminated soil removal Phytoremediation	€ € €€ € €€ €	Not recommended in GW-areas Not recommended close to surface water Phytoremed doesn't work in gravelbed-desing	
Anti-tank rockets/Recoilless rifles impact area	Small sized well defined area with energetics and copper from detonations, and metals (pb) in case of sub-caliber shooting. Pollutant mainly in the disturbed topsoil (tens of cm to 1 m). Possible elevated LO and dud rates, ricochets	Back berm behind the target Surface water runoff control Impermeable structure under the target	Regular EOD and cleaning Monitoring Periodical soil investigations Periodical contaminated soil removal	€€ € € €	Not recommended in GW-areas	
Artillery/Mortars firing point	Small well defined area with deposition in front of position from propellant. Pollutant (ropellants) solely in the topmost centimetres.	Erosion control, marked tracks Standard firing points preferred	Propellant burning trays Rotations, rest periods IR-heater for top soil Phytoremediation	€ € € €	Shooting close to SW should be avoided No significant contamination expected Firing points may not be stationary	
Rockets/Missiles firing point	Small-medium sized well defined area with pollutant from the propellant in the backblast area and deposition in front of position. Pollutant solely in the topmost centimetres	Standard firing points preferred Erosion control, marked tracks Impermeable structure at fp	Rotations, rest periods IR for top soil maintenance Phytoremediation	€ € €	Not recommended close to surface water Firing points may not be stationary	
Artillery/Mortars/Rockets /Missiles impact areas	Large-very large area with energetics/metals from detonations. Pollutant found from topsoil to several metres depth. Generally concentrated near fixed targets	Constructed wetland design Surface water runoff control	Regular EOD and cleaning Monitoring Dud rate recording Periodical soil investigations Rotation, rest periods Periodical contaminated soil removal	€€ € € €€ € €€€	Not recommended in GW areas Shooting on water prohibited	
Tank Gun/Autocannon firing areas	Mobile training often results in the establishment of consecutive firing positions. Each position consist of a small, well defined area with contamination in front of position (propellant). Pollutant solely in the topmost centimetres.	Erosion control, marked tracks	Avoidance of vulnerable ecosystems IR for top soil maintenance Monitoring	€ € €		

## Appendix 4E Descriptions of management options

4E.1	Monitoring Munitions Performance on Impact Ranges
4E.2	Rest Periods - Rotation of Locations of Training Exercises
4E.3	Portable Burn Pan for Excess Artillery Propellant
4E.4	Avoiding White Phosphorus Contamination of Surface Waters
4E.5	Water Management
4E.6	Cleanup of Metal Debris from Surface Soil Using High Power Magnet
4E.7	UV-Treatment of TNT and RDX Contaminated Groundwater

### 4E.1 Monitoring Munitions Performance on Impact Ranges



#### Description

Munitions do not always detonate as designed. Projectiles may fail to detonate (duds) or detonate incompletely (low-order and partial detonations). Artillery training units have forward observers to guide in fire to the target points and monitor detonations, but accurate munitions performance assessment and documentation rarely occur. The result is an inaccurate accounting of munitions performance on the impact range. To determine the environmental impact of live-fire training on military ranges, energetics

loading needs to be estimated, and as low-order and partial detonations of rounds dominate the deposition of energetics on ranges, a more accurate method of monitoring ranges for detonation efficiency is needed.

#### Efficiency

Properly trained personnel can easily distinguish detonations from duds. Differentiation between high-order, low-order, and partial detonations by eye and ear will require more skill, so initial determination of munition functionality may

not be as accurate as desired. The ability to differentiate between detonation types will improve with experience. Systems that can monitor and record impact locations and provide an estimate of projectile functionality have been developed and successfully field-tested. However, they have not been tested against an actual live-fire mixed-caliber training exercise.

### Applicability

This management control should be applied to all ranges into which munitions containing energetics are fired. Determination of munitions efficiency can be used to determine if the use of particular munitions should be limited or banned. These data will also be valuable for evaluating munitions for use in combat.

### Potential impacts

The presence of energetics ranges has led to restrictions on range use, range closures, and very large monetary liabilities. Inaccurate knowledge of the functionality of munitions will compromise military operations in time of war. The ability to distinguish the location of malfunctioning rounds will greatly aid in training range cleanup and sustainability.

### Availability

Manned monitoring of munitions impacts is currently done by military forward observers but needs to be changed by employing independent observers trained to determine the type of detonation that occurs for each round. Automated systems have not been developed to the point of availability. Additional research and development work may be required prior to the fielding of a commercial automated detonation monitoring system. Likely availability would be 5-6 years from the inception of development.

### Maintenance and monitoring

Automated systems will require periodic maintenance and recalibration, perhaps as often as seasonally to compensate for changing soil conditions.

### Costs

Both systems will require staff on site. A database will need to be maintained for recording the presence and location of improperly functioning munitions. The cost of an automated site monitoring system will need to be determined following final development.

## REFERENCES

- Dauphin, L, and C Doyle (2000) Report of Findings for Study of Ammunition Dud and Low-order Detonation Rates. Report SFIM-AEC-ET-CR-200049. US Army Environmental Center, San Antonio, TX USA
- Dauphin, L, and C Doyle (2000) Report of Findings for Phase II Study of Ammunition Dud and Low-order Detonation Rates. Report SFIM-AEC-PC-CR-200139. US Army Environmental Center, San Antonio, TX USA
- Walsh, MR, ME Walsh, I Poulin, S Taylor, and TA Douglas (2011) "Energetic residues from the detonation of common US ordnance" *Int. J. Energ. Mater. Chem. Propul.* 10(2): 169-186.

### Recommendations

- Keep accurate records of munitions fired into training range impact areas
- Train independent forward observers to monitor heavy weapons training exercises
- Monitor the functioning of the rounds (high-order, low-order, dud)
- Report malfunctioning or nonfunctioning rounds
- Develop automated detonation monitoring systems for impact areas

## 4E.2 Rotation of locations of training exercises, rest periods



### Description

Some energetic residues undergo natural attenuation under environmental conditions. By designating rest periods between training activities, accumulation of residues can be minimized.

### Efficiency

The efficiency of this method will depend on the site conditions and will be greatest in locations that have anaerobic soils/sediments.

### Applicability

This method is most applicable to training activities that result in the deposition of energetic residues that are not persistent in the environment. Examples of these residues include DNT and NG at firing points and TNT in impact areas. The rate of deposition must be lower or equal to the rate of attenuation to prevent accumulation.

### Potential impacts

*Environmental impacts:* None.

*Effect on training:* The training range needs to be large enough to accommodate multiple firing points.

### Availability

This method requires accurate records of the locations of training so that the same location is not used over and over. Action levels for energetic residues in soil/sediment would need to be designated for each training site.

### Maintenance and monitoring

Periodic soil sampling is needed to monitor the accumulation of energetics.

### Costs

Normal costs associated with maintaining training range records

## REFERENCES

Bordeleau, G., R. Martel, G. Ampleman, S. Thiboutot, I. Poulin. The fate and transport of nitroglycerin in the unsaturated zone at active and legacy anti-tank firing positions. *Journal of Contaminant Hydrology* 1420143 (2012) 11-21.

Jenkins, T.F. and C. Vogel. Department of Defense Operational Range Sustainability through Management of Munitions Constituents. Technical Report to SERDP/ESTCP (2014)

Low, Darryl, K. Tan, T Anderson, G.P. Cobb, J. Liu, W.A. Jackson. Treatment of RDX using down-flow constructed wetland mesocosms. *Ecological Engineering* 32 (2008) 72-80

### Recommendations

This method is most applicable to mortar and howitzer firing points where deposition of propellant residue containing DNT and/or NG is low enough that the rate of accumulation can be managed using natural processes.

Deposition at firing points and impact areas of anti-tank ranges is too high to rely on this technique alone and require additional management. In mortar and artillery impact areas, RDX and HMX will persist longer than TNT, and will migrate to groundwater unless the soils are anaerobic. For example, anti-tank ranges need management because of the high rates of deposition at the firing point and impact area. Demolition ranges where C4 is used and impact areas into which Comp B is fired will have residues of RDX. RDX has a high likelihood to migrate to groundwater unless the soils/sediments are anaerobic.

This method can be used in conjunction with more active mitigation methods such as soil amendments or constructed wetlands to treat surface water.

### 4E.3 Portable Burn Pan for Excess Artillery Propellant

#### Description

On artillery ranges where heavy weapons are used, propelling charges are issued with each projectile. As a result of range and equipment restrictions, not all propelling charges are fully consumed during training. Excess propellant charges are burned on site by troops as part of their training, which may result in energetic and heavy metals residues. Burn pans are portable training devices, allowing propellant charges to be loaded and burned in a controlled setting. Burn pans increase the efficiency of propellant disposal and greatly reduce the deposition of energetics and heavy metals at artillery range firing points.

#### Efficiency

The burn pan is a stand-alone training device that will increase burn efficiency of excess propellant. Loads of up to 120 kg of propellant have been burned in one shot. The reduction in total mass of charge bags is 99.98%. The reduction in energetics is >99.99%. Energetics comprise <1% of the ash recovered from the pan following training. There was no detectable increase in energetics or lead in the soil within the 6-m annulus surrounding the pan following three field tests. Unit cycle time (burn to burn) is 12 – 15 minutes.

#### Applicability

The burn pan is designed for use by training artillery units that generate excess propellant charges. It can be used at the firing point on which the training is taking place or at a location central to the training unit. All types of artillery propellant can be burned in the pan. At 120 kg, it is easily transported to the sites.

#### Potential impacts

The field-portable burn pan greatly reduces the environmental impact of artillery training. Prior methods of open burning following training resulted in up to 20% of the propellant surviving the burns. The burn pan reduces energetics deposition and contamination by four orders of magnitude.

Training is enhanced through the use of the burn pan. Soldiers can now conduct training near their firing positions in a more controlled manner without the hazardous transportation of energetics over long distances on unimproved roads. Burning in lifts allows multiple teams to train on propellant disposal.

The burn pan facilitates range management for sustainability. Burns occur in a controlled manner, and residues are easily collected and processed, if necessary. Residues are unmixed with soils, making content determination much simpler.

#### Availability

The burn pan is an existing piece of equipment currently being used at three military bases in the US. It has been tested over five years, with test documentation available to potential users. The burn pan technology is fully developed. Several publically available reports are out describing the technology. Machine drawings of the pan are available to interested parties.

#### Maintenance and monitoring

Little maintenance is required of the pans. Residues should be collected at the end of each training exercise and the device inspected for any damage. The device should be stored in a protective structure.

#### Costs

The cost of the device is determined by the number fabricated. Single-unit fabrication will run about \$10K.

### REFERENCES

- ESTCP Project ER-201323 (Completed 2015).
- Thiboutot, S, G Ampleman, D Pantea, S Whitwell, and T Sparks (2012) Lead emissions from open burning of artillery propellants. *Air Pollution XX 157* (2012): 273 – 284.
- US Army National Guard (2012) Best Management Practices for Army National Guard Operational Ranges: Burn Pans. ARNG Fact Sheet.
- Walsh, MR, Walsh, ME, and Hewitt, AD (2009) Energetic residues from the expedient disposal of artillery propellants. ERDC/CRREL TR-09-8 US Army Cold Regions Research and Engineering Laboratory, Hanover, NH, USA. (Available on-line)
- Walsh, MR, ME Walsh, and AD Hewitt (2010) Energetic residues from field disposal of gun propellants. *Journal of Hazardous Materials*, 173: 115-122.
- Walsh, MR, S Thiboutot, ME Walsh, and G Ampleman (2012) "Controlled expedient disposal of excess gun propellant" *Journal of Hazardous Materials*, 219-220: 89-94.
- Walsh, MR (2013) Test report: CRREL portable propellant burn pan – Prototype burn test, Camp Grayling, MI. US Army Cold Regions Research and Engineering Laboratory, Hanover, NH, USA.
- Walsh, MR (2014) Test report: CRREL portable propellant burn pan – Prototype burn test, Fort Indiantown Gap, PA. US Army Cold Regions Research and Engineering Laboratory, Hanover, NH, USA.

Walsh, MR (2015) Test report: CRREL portable propellant burn pan – Test and demonstration of final version of pan, Donnelly Training Area, Alaska August 2015. US Army Cold Regions Research and Engineering Laboratory, Hanover, NH, USA.

### Recommendations

Use the field-portable excess propellant burn pan training device during all artillery training exercise for which excess propellant is generated and when training of soldiers on expedient burning of propellant charges in the field is required.

## 4E.4 Avoiding White Phosphorus Contamination of Surface Waters

### Description

White phosphorus (WP) is used by the military as an obscurant material. It is also used for targeting during artillery training, forming a moving target at which training units can fire. Although highly pyrophoric, not all WP is consumed upon detonation. Mass deposition varies according to the surface of the areas into which the munitions are fired. Dry upland areas are conducive to efficient consumption of WP, whereas areas containing surface water will reduce consumption efficiency. Snow and wet vegetation will also adversely affect residue accumulation. To best control WP contamination of ranges, training should be directed toward areas that do not contain surface moisture, snow, or water. Firing of WP during or immediately following rainfall events or when the ground is snow-covered should be avoided on upland ranges.

### Efficiency

Persistence of WP is prolonged by cold and wet conditions. Avoidance of firing into wet or ponded areas will minimize the mass of WP remaining on ranges. In an impact range located on an estuarine salt marsh in Alaska, over 20% of the white phosphorous load of 81-mm munitions fired into areas of permanent standing water remained following detonation of the rounds. The WP remained in the saturated soils and submerged vegetated areas for over 20 years with no apparent significant attenuation of mass. By contrast, upland deposited WP attenuates over time, the rate dependent upon the presence of moisture on the soil and vegetation. Persistence of large pieces of WP on dry land is possible if oxidation products form a crust that prevents sublimation.

### Applicability

This management control should be applied to all ranges into which WP is fired and on which surface water, snow, or rainfall that wets the soil or vegetation precipitation occurs.

### Potential impacts

The presence of residual white phosphorus on a range can lead to environmental impacts to the local and introduced fauna. Widespread deaths of waterfowl and Bald Eagles on the Alaska impact range resulted in the temporary loss of the range, environmental liabilities of around €50M, and restrictions on range use that have lasted over 25 years. Redirecting training fire generally costs nothing, unless there are no appropriate areas into which WP can be fired and training must be conducted elsewhere.

### Availability

This control method is immediately implementable.

### Maintenance and monitoring

No maintenance is required. However, careful monitoring of activities may need to occur to ensure the guidance is being followed.

### Costs

There are no costs associated with implementing this guidance. Deployment costs may occur if training must be conducted with WP and there is no appropriate area on base into which WP can be fired.

## REFERENCES

Walsh, MR, ME Walsh, and ØA Voie (2014) Presence and persistence of white phosphorus on military training ranges. *Propell, Explos, Pyrot.*, 39:922-931.

Walsh, ME, MR Walsh, CM Collins, CH Racine (2014) White phosphorus contamination of an active army training range. *Water, Air, Soil Poll.*, 225(6), 1-11.

Walsh, MR, JE Zufelt, and CM Collins (2006) Remediation of white phosphorus contamination in an Alaskan wetland. *J. Environ. Eng. Sci.*, 5(1): S87-S93.

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ME Walsh, CM Collins (1993) Distribution of white phosphorus residues from the detonation of 81-mm mortar WP smoke rounds at an upland site. CRREL Special Report 93-18, USA CRREL, Hanover, NH, USA.

CH Racine, ME Walsh, BD Roebuck, CM Collins, DJ Calkins, LR Reitsma, PJ Buchli, G Goldfarb (1992) White phosphorus poisoning of waterfowl in an Alaska salt marsh. *J. Wildlife Dis.*, 28(4): 669-673

## Recommendations

- Restrict the use of munitions containing white phosphorous to ranges that have no surface water and that have soils that are dry to periodically dry.
- Do not use WP rounds when snow or ice is present on the ground.
- Monitor ranges that contain wetlands or surface waters and into which WP rounds were fired for waterfowl mortalities.

## 4E.5 Water Management



### Description and Efficiency

Water management can be divided to water handling (collection and conduction) and water treatment. Some water handling methods affect also transport and natural decomposition of harmful substances and are described in this info card.

There are several basic methods to water handling (rainwater, groundwater, surface water) for preventing water contamination and transport of contaminants. Primary method is to prevent or reduce interaction of water and contaminated material (usually soil). It can be implement by locating activity for example to terrain where moisture content is low, or with structures which channel waters (for example side ditches and drainages) so that outside waters do not pass the most contaminated areas.

Secondary method is to collect water which possible contain harmful substances. Collection can be done with ditches or

underground drainages. In constructed areas, different kind of waterproof structures can be installed to enhance water collection efficiency. Waterproof structures can be made on the ground surface (concrete or asphalt) or underground (plastic liners, bentonite or clay). Heavy weapons special features (shock wave, penetration) should be noticed when planning the structures. Collected water can be conducted further a) for monitoring or b) to areas which are not so sensitive, or c) for treatment if necessary.

If range site is located in area with natural or manmade ditches, waterflow can be modified to reduce transportation and to enhance natural degradation of harmful substances. Methods are similar than those in forestry water management and can be used in relatively large areas and water amounts. Methods include *blocking of ditches, sludge and sedimentation basins, flow control dams, surface runoff fields, constructed wetlands and organic filters.*

Forestry water management methods have limited mitigation capability. Reduction is based on 1) absorption of compounds mostly in organic matter and plants and 2) slowing down water flow, which reduces flood/flushing effects and improves degradation of harmful substances.

### Applicability and Recommendations

At maneuver ranges water contamination is rarely issue, because surface area is large compared to amount of contaminants. In some cases contamination load can be reduced by water channeling structures or by selecting best available location for activity, especially when designing new training area.

Use of collection structures for waters from contaminated sites is economically reasonable only at Qualifying ranges. For example liners can be installed in ground at firing points and backberms. Protective liners, water collection and treatment structures can be installed also at anti-tank ranges and disposal ranges.

Some forestry water management methods (blocking of ditches, sludge and sedimentation basins) effect mostly in substances such as heavy metals and nutrients, which are absorbed to organic matter. To achieve best effect in mitigation, it is recommended that several methods are combined. Flow control structures, as *peak runoff control dam*, *stoplogs*, *sludge well*, *V dam* and *other regulation dams* enhance other water protection structures functionality and reduces erosion. Spatial data tools should be used for planning the structures and to improve *controlled conduction and delaying of water flow*.

Surface runoff fields and constructed wetlands are most useful of forestry water management methods. If training area or ground downstream are rich of organics matter (for example peat soil) or suitable vegetation (for example willow), methods are well suited as sole water protection solutions for the training areas.

### Potential impacts

Water handling structures can have negative effects to nature values, because those often require large excavations influencing water levels, which can change biotopes in the area. Structures can be planned so that there is no negative effect on training circumstances. In wet areas, water handling can enhance training circumstances.

### Availability

There are several methods which are used in certain training areas as shooting backberms, fire training etc. Knowledge of methods and structures can be benefit in heavy weapon

training areas. Lots of different kinds of materials for structures are commercially available.

Forestry water management methods are extensively used in Nordic countries. However, these methods have not been widely used at military areas. Experience gained by the mining industry of wetlands and surface runoff fields that reduce heavy metal loads is encouraging.

### Maintenance and monitoring

Water handling structure needs maintenance, but it doesn't have to be intensive. Structures inspection interval should be 2-5 years, focus in the sediment of ponds and vegetation. Clean up can be challenging, but the interval is usually several decades. Water management structures improve the ability to monitor effects on the water systems.

### Costs

Costs vary strongly depending of method used. For example underground liner costs are approximately 20-200 €/m<sup>2</sup> and drainage systems 2-50 €/m. Forestry methods are relatively cheap. Dam structures in a ditch cost approximately 5000-20000 €.

## REFERENCES

Joensuu S. & Hyvärinen A. (2017).  
Forestry Surface Water Management  
Methods applied in Environmental  
Protection of Military Ranges

#### 4E.6 Cleanup of metal debris from surface soil using high power magnet



##### Description

Old heavy weapons target areas, OB/OD as well as explosives training sites may have accumulated loads of metallic debris on the surface soil. For environmental maintenance of the site it is advisable to periodically collect the residues of metallic ammunition and grenades from the soil by using high power magnet.

##### Efficiency

High power magnet is very efficient in harvesting magnetizing metals (iron, nickel) from the top soil. Depending on the soil type and debris, metal fragments can be pulled up from the depth of 5 - 15 cm. Magnet can also be used cleaning under water objects from the sediment. In the pilot test in an old target area, the catchment of the small metal fragments was in average 0,8 - 1 kg/m<sup>2</sup>. Approximated speed for magnet cleanup is about 200 m<sup>2</sup>/h.

##### Applicability

Magnet can be used for cleaning the top soil from metallic debris. Since ammo shells and many alloys contain iron, most of the ammunition waste can be harvested. Clean up does not affect the concentrations of the heavy metals in the soil, so it cannot be used for soil remediation. Also, in many sites it is mandatory to do EOD before cleanup. Dense vegetation and rocky terrain may affect the speed and efficiency of the work.

##### Costs

Need of labor 2 – 4 workers. Magnet is connected to backhoe, so the machinery can be obtained inside the military.

##### Recommendations

Recommended for site cleanup and maintenance, not recommended for contaminant remediation.

#### REFERENCES

Koponen, K., Luhtio, H., and Pasanen, T. (2016). Pilot test of high power magnet cleanup on an old military site. CEDA Report.

#### 4E.7 UV-Treatment of TNT and RDX Contaminated Groundwater



##### Description

Ultraviolet irradiation (UV) is frequently used purification and disinfection method at the municipal waterworks. Purpose of the experiment was to evaluate the efficiency of UV irradiation to degrade energetic compounds in water under standard conditions used at waterworks.

##### Study design

Tests were run using Wedeco Aquada Proxima 7 equipment (UV chamber water volume 6,3 l). Efficiency of UV irradiation was tested with 407 J/m<sup>2</sup> and 550 J/m<sup>2</sup> UV doses (water flows 6,2 m<sup>3</sup>/h and 4,5 m<sup>3</sup>/h). The dosages were chosen to corresponding practices at water stations. Initial volume of 1 m<sup>3</sup> of water spiked with TNT (27 µg/l) and RDX (35,7 µg/l) was prepared for the test.

##### Results

Analytical results of the water before and after each UV-irradiation test are shown in the table 1.

As a result, about 30 % of TNT and 37 % of RDX were degraded under 407 J/m<sup>2</sup> dose. With higher dose (550 J/m<sup>2</sup>) degradation rate was the same for TNT (30 %), but notably higher for RDX (47 %). Small amounts of degradation products of TNT were evident in initial water solution (TNB and 4-ADNT). In irradiated water the concentrations of TNB increased, indicating the active degradation process of TNT.

##### Applicability

TNT and RDX are degraded by UV irradiation, but not efficiently enough for utilization of UV as sole treatment method for explosives contaminated water at waterworks. However, the concentrations used in the test were considerably higher than at the military sites where energetics have been detected in groundwater. It is estimated, that with lower concentrations and higher UV-dosages energetics could be irradiated more effectively.

##### Costs

Not assessed for this test. The use of UV-irradiation is estimated to be of low cost, since it is commonly in use in various industrial and household applications.

##### Recommendations

Further testing with higher dosages and environmentally realistic concentrations of energetics is recommended. The UV-radiation unit is a common device at municipal waterworks and therefore can be activated without delay for acute groundwater risk management. Long-term use of UV-irradiation in water purification is also estimated to be cost-effective.

#### REFERENCES

Aalto, J. (2016) Management of the groundwater contaminated by military explosives. Master of Science Thesis. Tampere University of Technology.

**Table 1.** Concentrations of TNT, RDX and degradation products TNB and 4-ADNT before and after UV irradiation (µg/l).

	DL*	Initial conc.	400 J/m <sup>2</sup>	540 J/m <sup>2</sup>
TNT	0.1	27.0	19	19
RDX	0.2	35.67	22.5	19
TNB	0.1	0.93	3.2	3.25
4-ADNT	0.1	0.14	-	-

\*DL, detection limit

