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2.6 Risk categorization procedures

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2.6.1 Creation of list of risk chemicals and their categorization.

Chalmers have taken the most common chemical warfare agents (CWA) included in the dumped munitions in the Baltic Sea area, and searched in the literature for the most usable measure for categorize their toxicity. To incorporate the toxicity of CWA into VRAKA-CWA you need to be able to normalize the toxicity. In addition, the scientific basis of toxicity of chemical warfare agents and conventional munitions is often low. Then a proxy of toxicity is needed to be used, e.g. QSAR (Quantitative structure–activity relationship), bioconcentration factors (BCF) or toxic units (TU). Chalmers decided to use toxic units to create a list of risk chemicals and risk categorize them. Toxic units are derived by scaling a measured compound concentration to its effect concentration in a standard test system. Then, single chemicals can be compared to each other or added to an overall effect. For evaluation of TUs acute endpoints are commonly used, and PEC/PNEC ratios are used for chronic endpoints. Often standard test organisms, for example *Daphnia magna*, *Pseudokirchneriella subcapitata* or *Pimephales promelas* are used as model organisms for algae, daphniids and fish. Then a LC50 concentration of 10µM means that the 1TU is 10µM. For example, Sanderson et al (2007, 2010) estimated TU for CWAs (Table 1).

Table 1. Predicted TU of common CWAs (Sanderson 2007, 2010).

CWA	TU (primary/secondary)
Chloroacetophenone (CAP)	0,0059/0,0012
Sulfur mustard gas (Yperite)	0,4/0,083
Adamsite	0,81/0,17
Clark I	0,41/0,086
Triphenylarsine	1,03/0,2
Phenyldichloroarsine	0,057/0,011
Trichlorarsine	0,0056/0,0011
Zyklon B	0,36/0,059
Monochlorobenzene	0,070/0,012

In addition, the most common explosive used in conventional munitions is Trinitrotoluene (TNT). Toxic units for TNT (0.268) and its degradation products were located in the literature (Liu 1983)(Table 2).

Table 2. Toxic units (TU) for TNT and degradation products.

Substance	TU
2,3,6-Trinitrotoluene	0.268
1,3-Dinitrotoluene	4.000
2,4-Dinitrotoluene	14.700
2,6-Dinitrotoluene	7.300
3,4-Dinitrotoluene	0.500
5-Amino-2,4-dinitrotoluene	0.700

2,5-Dinitrotoluene	0.400
Toluene	0.200

VERIFIN has provided a list of chemicals that will be analyzed from sediment samples that has been sampled, by project partners, at dumpsites. It includes both CWA related and explosive related chemicals (Table 3).

Table 3. Chemicals that is being analyzed by VERIFIN.

Chemical	Category	Type
Sulfur mustard	Intact chemical	CWA related
Thiodiglycol	Sulfur mustard-related degradation product	CWA related
Thiodiglycol sulfoxide	Sulfur mustard-related degradation product	CWA related
1,4-Dithiane	Sulfur mustard-related degradation product	CWA related
1,4-Oxathine	Sulfur mustard-related degradation product	CWA related
1,4,5-Oxadithiepane	Sulfur mustard-related degradation product	CWA related
1,2,5-Trithiepane	Sulfur mustard-related degradation product	CWA related
Thiodiglycolic acid	Sulfur mustard-related degradation product	CWA related
Adamsite	Intact chemical	CWA related
5,10-Dihydrophenarsazin-10-ol 10-oxide	Adamsite-related degradation product	CWA related
10-Methyl-5H-phenarsazinine 10-oxide	Adamsite-related degradation product	CWA related
10,10'-Oxybis(5,10-dihydrophenarsazinine)	Adamsite-related degradation product	CWA related
Clark I	Intact chemical	CWA related
Diphenylarsinic acid	Clark-related degradation product	CWA related
Methyldiphenylarsine oxide	Clark-related degradation product	CWA related
Bis(diphenylarsine)oxide	Clark-related degradation product	CWA related
Triphenylarsine	Component in dumped arsine oil	CWA related
Triphenylarsine oxide	Triphenylarsine-related degradation product	CWA related
Phenylarsonic acid	Phenyldichloroarsine-related degradation product	CWA related

α -Chloroacetophenone	Intact chemical	CWA related
Bis(2-chlorovinyl)arsinic acid	Lewisite-related degradation product	CWA related
Methyl N,N-dimethyl phosphoramidate	Tabun-related degradation product	CWA related
O,O'-Diethyl N,N,N',N'-tetramethyl-P,P'-diphosphordiamidate	Tabun-related degradation product	CWA related
2,4,6-trinitrotoluene (TNT)	Explosive (intact chemical)	Explosive related
1,3,5-trinitro-1,3,5-triazine (RDX)	Explosive (intact chemical)	Explosive related
1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane (HMX)	Explosive (intact chemical)	Explosive related
N-methyl-N-2,4,6-trinitroaniline (Tetryl)	Explosive (intact chemical)	Explosive related
Pentaerythritol tetranitrate (PETN)	Explosive (intact chemical)	Explosive related
Glycerin trinitrate (Nitroglycerin, NG)	Explosive (intact chemical)	Explosive related
4-methyl-3,5-dinitroaniline	TNT-related degradation product	Explosive related
2-methyl-3,5-dinitroaniline	TNT-related degradation product	Explosive related
2,4,6-triaminotoluene	TNT-related degradation product	Explosive related
2,4-Dinitrotoluene	TNT-related degradation product	Explosive related
2,6-Dinitrotoluene	TNT-related degradation product	Explosive related
2-Nitrotoluene (2-NT)	TNT-related degradation product	Explosive related
3-Nitrotoluene (3-NT)	TNT-related degradation product	Explosive related
4-Nitrotoluene (4-NT)	TNT-related degradation product	Explosive related
Nitrobenzene	TNT-related degradation product	Explosive related

MUT has also provided a list of chemicals, including both CWA related and explosive related compounds that they are able to analyze (Table 4).

Table 4. Chemicals that is being analyzed by MUT.

#	Chemical compound (acronym)	Description
	CAS	
1	Sulfur mustard (H)	Dumped CW agent
	505-60-2	
1.1	Thiodiglycol (TDG)	Hydrolysis product of 1
	111-48-8	
1.1S	Bis(2-siloxyethyl)sulfide	BSTFA derivative of 1.1
	20486-03-7	
1.1O	Thiodiglycol sulfoxide	Oxidation product of 1 (either natural or with H ₂ O ₂)
	3085-45-8	
1.1OS	Bis(2-siloxyethyl)sulfoxide	BSTFA derivative of 1.1O
	97916-03-05	
1.2	1,4-Dithiane	Degradation product of 1
	505-29-3	
1.3	1,4-Oxathiane	Degradation product of 1
	15980-15-1	
1.4	1,4,5-Oxadithiepane	Degradation product or by-product of 1
	3886-40-6	
1.5	1,2,5-Trithiepane	Degradation product or by-product of 1
	6576-93-8	
1.6	Thiodiglycolic acid (TDGA)	Bacterial metabolite of 1.1
	123-93-3	
1.6S	Bis(trimethylsilyl) 2,2'-thiodiacetate	BSTFA derivative of 1.6
	20486-03-7	
2O	5,10-Dihydrophenoarsazin-10-ol 10-oxide	Oxidation product of 2 and all of its degradation products (either natural or with H ₂ O ₂)
	4733-19-1	
3a	Clark I (DA)	Dumped CW agent. Also component in dumped arsine oil.
	712-48-1	
3O	Diphenylarsinic acid	Oxidation product of 3a and 3b and all of their degradation products
	4656-80-8	

		(either natural or with H ₂ O ₂)
3T	Diphenylpropylthioarsine	Derivative of 3a and 3b and all of their degradation products
	17544-92-2	
4	Triphenylarsine (TPA)	Component in dumped arsine oil
	603-32-7	
4O	Triphenylarsine oxide	Oxidation product of 4 and all of its degradation products
	1153-05-5	(either natural or with H ₂ O ₂)
5O	Phenylarsonic acid	Oxidation product of 5 and all of its degradation products (either natural or with H ₂ O ₂)
	98-05-5	
5T	Dipropyl phenylarsonodithioite	Derivative of 5 and all of its degradation products
	1776-69-8	
6	α-Chloroacetophenone (CN)	<i>Dumped CW agent</i>
	532-27-4	
7O	2-Chlorovinylarsonic acid	Oxidation product of 7 and all of its degradation products (either natural or with H ₂ O ₂)
	64038-44-4	
7T	Dipropyl (2-chlorovinyl)arsonodithioite	Derivative of 7 and all of its degradation products
	677354-97-1	
8O	Bis(2-chlorovinyl)arsinic acid	Oxidation product of Lewisite II and all of its degradation products (either natural or with H ₂ O ₂)
	157184-21-9	
8T	Bis(2-chlorovinyl) propylthioarsine	Derivative of Lewisite II and all its degradation products
	677355-04-3	
9	2,4,6-Trinitrotoluene (TNT)	<i>Dumped explosive, component of many explosive compositions used during WWII</i>
	118-96-7	
9.1	4-Nitrotoluene (4-NT)	<i>Degradation products and impurity of 9</i>
	99-99-0	
9.2	1,3-Dinitrobenzene (1,3-DNB)	<i>Degradation products and impurity of 9</i>
	99-65-0	

9.3	1,3,5-Trinitrobenzene (1,3,5-TNB)	<i>Degradation products and impurity of 9</i>
	99-35-4	
9.4	2,4-Dinitrotoluene (2,4-DNT)	<i>Degradation products of 9</i>
	121-14-2	
9.5	2,6-Dinitrotoluene (2,6-DNT)	<i>Degradation products of 9</i>
	606-20-2	
9.6	2,4-Dinitroaniline (2,4-DNA)	<i>Degradation products of 9</i>
	97-02-9	
9.7	4-Amino-2,6-dinitrotoluene (4A26DNT)	<i>Degradation products of 9</i>
	19406-51-0	
9.8	2-Amino-4,6-Dinitrotoluene (2A46DNT)	<i>Degradation products of 9</i>
	35572-78-2	
9.9	2,4,6-Trinitrobenzoic acid (TNBA)	<i>Degradation products of 9</i>
	129-66-8	
10	1,3,5-Trinitro-1,3,5-triazinane (RDX)	<i>Dumped explosive, component of many explosive compositions used during WWII</i>
	121-82-4	
10.1	N,N'-dinitromethanediamine (MEDINA)	<i>Degradation product of 10 and 11</i>
	14168-44-6	
10.2	Hexahydro-1,3,5-trinitroso-1,3,5-triazine (TNX)	<i>Degradation product of 10 and 11</i>
	13980-04-6	
11	1,3,5,7-Tetranitro-1,3,5,7-tetrazocane (HMX)	<i>Dumped explosive, component of explosive compositions used during WWII, impurity of RDX</i>
	2691-41-0	
12	Pentaerythritol tetranitrate (PETN)	<i>Dumped explosive, component of detonators used during WWII</i>
	78-11-5	
13	Glycerin trinitrate (NG)	<i>Dumped explosive, component of propellants and smokeless powders</i>
	55-63-0	
13.1	Glycerin dinitrate (DNG)	<i>Degradation product of 13</i>
	621-65-8	
13.1	Glycerin nitrate	<i>Degradation product of 13</i>
	624-43-1	

2.6.2 Development of leakage scenarios and their categorization

FFI has conducted experiments that models the contamination of chemical warfare agents (CWA) and their release rates from munition shells. The time before the shells are perforated depends on several factors, like the thickness of the shell, the quality of the metal, the physical parameters in the area e.g. temperature, salinity, pH and corrosion rate. Furthermore, the rate of corrosion is also influenced by contact with other metals. Once a CWA is released into the water parameters such as density, water solubility and the agent's stability in water is important. The stability of chemical agents in sea water differs (Table 5). Mustard agent will stay on the seabed for decades and form lumps with a hard cover, and active Yperite will still be contained inside the shell of the lump. Organoarsenic agents do not degrade and will stay on the sea-floor and can possibly be taken up and accumulated in marine organisms. Heavier-than-water chemical warfare agents like Clark I and Clark II will not disperse far from the munition shells if the sediments aren't disturbed. The nerve agent tabun has a density close to water, is soluble in water and is the most acute toxic CWA compound dumped in Skagerrak. It is quickly diluted and decomposed to less toxic compounds. Therefore, it is of interest to determine the release rate of tabun from a corroded bomb shell.

Table 5. Various chemical warfare agents and their solubility and stability in water.

Agent	Density	Solubility in water	Stability in water
Nerve agents (tabun)	Like water	Good	Breaks down quickly
Phosgene	Heavier than water	Good	Breaks down quickly
Mustard agents (Yperite)	Heavier than water	Poor	Poorly soluble, what is solved decomposes quickly
Chloracetophenone	Heavier than water	Poor	Reacts slowly
Organoarsenic agents	Heavier than water	Poor	Stable

An experiment was therefore carried out to determine the release rate of tabun. A full-size model of a KC250 III Gr. aerial bomb was made in aluminum with Plexiglas in one end. The bomb model had circular openings with different sizes (2.5 cm², 5 cm² and 10 cm²). The bomb was filled with fresh water or a tabun simulant, immersed in sea water in a tub at room temperature. A water current in the tub was generated by a small propeller and the velocity measured at different distances from the bomb. Water conductivity was measured both inside and outside the bomb.

Results show that 0.13 % of the volume had leaked out during 196 hours with a 10 cm² circular opening, which equals a mean release rate of 0.6 mL simulant/hour. The half-life of tabun is 8.5 h at 20 °C in seawater (Hoenig 2007). Most of the tabun will therefore hydrolyze before it leaks out of the bomb shells.

Chalmers have worked on leakage scenarios or scenarios which can affect leakage, to be included in the VRAKA-CWA risk assessment tool. In the tool there are four categorization scenarios that will be included: when units are dispersed and lying on the sediment surface, units embedded within the sediment, units inside a wreck, and when units are clustered in a pile of munitions (Fig. 1).

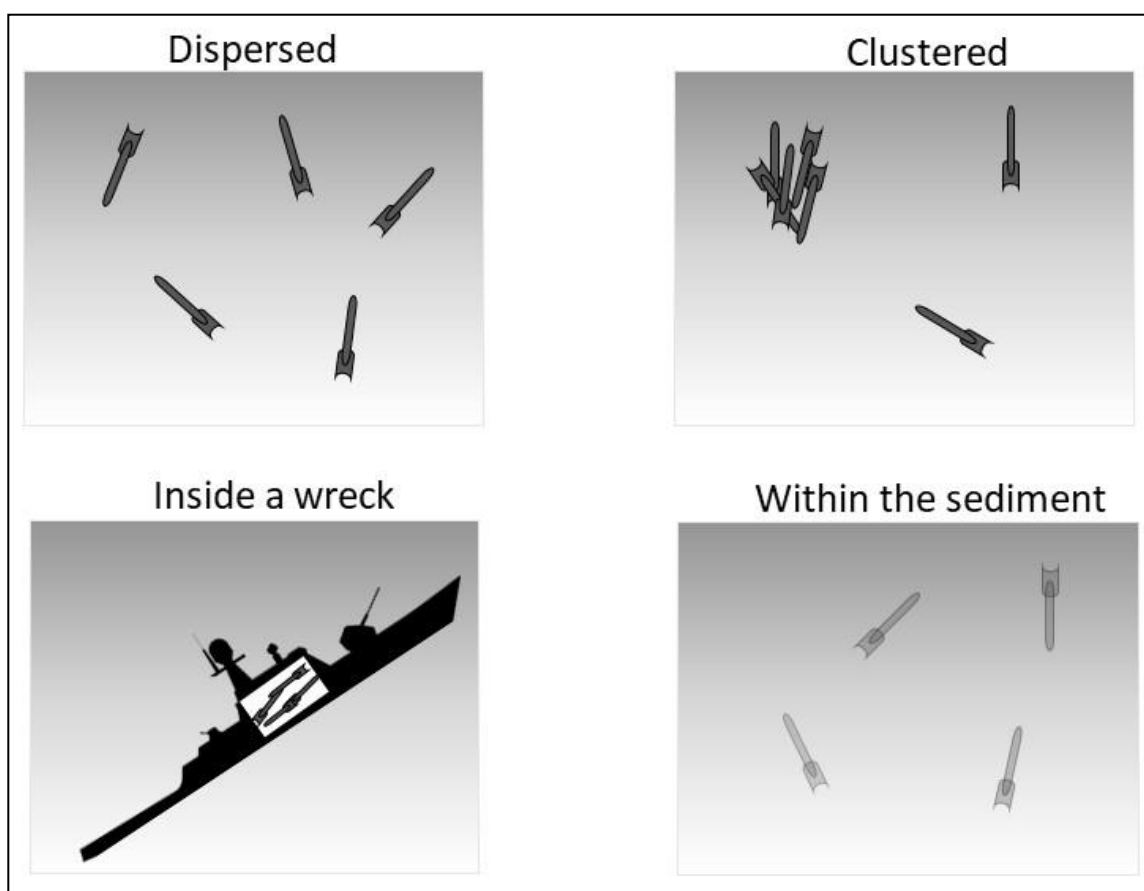


Figure 1. Categorization scenarios of units.

These scenarios are implemented into the VRAKA-CWA. A workshop was held (14th of March 2018) during the 5th DAIMON meeting. Experts were given the task to estimate the relative probability of release due to different activities relative to the reference case, when the dispersed scenario was the reference case. Results were analyzed and then implemented into the VRAKA-CWA tool.

PNA have conducted three types of corrosion tests. The aim of these tests was to assess the corrosion rate of ammunition bodies. The results are then implemented in the leakage scenarios of dumped chemical and conventional munitions.

Materials in the form of coupons, were used during the research. The steel material was selected ensuring that the production technology and the chemical composition was as similar as possible to the construction materials of ammunition, which was produced before and during World War II. The composition and structure of the coupon materials was established using literature data and studies carried out using EDS (Energy Dispersive X-ray Spectrometer) on museum items of artillery shells and aircraft bombs from WWII.

Three corrosion study experiments were then carried out, two laboratory studies and one in-situ study.

1. Laboratory study no. 1. Coupons were exposed for about one year, in three types of marine environments – samples were taken from the chemical ammunition dumping areas in the Baltic Sea. The experiment was carried out in temperatures at the seafloor from which the environmental samples were collected, i.e. 5°C. The pressure during the experiment corresponded to the atmospheric pressure. The three different environments were:
 - Sea floor sea water;
 - Sediment samples collected from layer 0-5 cm;
 - Sediment samples collected from layer 6-20 cm.
2. Laboratory study no. 2. Coupons were exposed in an accelerated environment, in a pressure chamber, with the same three types of marine environments as in the experiment above. The study lasted for 30 days and was performed in a temperature of 90°C. Conditions corresponded to 30 years of deposition of materials in the natural Baltic Sea environment.
3. In-situ experiment. Coupons were exposed for approximately one-year, mounted on specially prepared racks, in dumping areas of chemical and conventional munitions. The areas were Bornholm Deep, Słupsk Furrow and Gdańsk Deep.

In total eight types of materials were used for the experiments and the number of replicates from each material ranged between 36-8. After the experiments the corrosion rate was determined on the basis of weight loss of exposed corrosion coupons.

Results from laboratory experiment 1 showed an average corrosion rate of 0.0254 mm/year in sea water, compared to average corrosion rate of 0.0861 when the coupons were exposed to sediment. Results from laboratory experiment 2 showed a varying corrosion rate, with a range of 0.0021 mm/year to 0.0001 mm/year (Table 6).

Table 6. The range of corrosion rates (mm/year) of materials used in laboratory experiment 2.

No.	Type of container used for coupons	Corrosion rate (mm/year)	
		Sea floor water	Sediment
1	Barrel	0.0003– 0.0006	0.0004 – 0.0006
2	Steel sheet similar in composition to the material from which the aircraft bombs were produced	0.0001 – 0.0005	0.0003 – 0.0021

Results from the in-situ experiment showed varying corrosion rates at the different dumpsites and for the different materials used in the coupons. The corrosion rate at the Bornholm site was 0.0952 mm/year and 0.0243 at the Gdansk deep, for coupons made out of barrel material. In coupons made out of artillery projectile shells the corrosion rate was 0.0808 mm/year in Słupsk Furrow and 0.1210 mm/year in Bornholm Deep. In the coupons made out of steel sheet the corrosion rate was 0.0179 mm/year in Gdańsk Deep, 0.1071 mm/year in Słupsk Furrow and 0.1002 mm/year in Bornholm Deep (Table 7).

Table 7. The range of corrosion rates (mm/year) of materials from the in-situ study.

No.	Type of container used for coupons	Corrosion rate (mm/year)
		Sea water
1	Barrel	0.0243 – 0.0857
2	Artillery projectile 75 mm project Jgr 18 AB	0.0808 – 0.1210
3	Steel sheet similar in composition to the material from which the aircraft bombs were produced	0.0179 – 0.1071
4	Aluminium	0.0003 – 0.0093

2.6.3 Categorization of factors affecting the spreading of the chemicals in different conditions

Actions were taken to connect VRAKA-CWA and the Decisions support tool (DSS) developed by Clausthal (TUC) with models able to handle modeling of dispersion of CWA: s, just as the VRAKA tool that deals with shipwrecks that contain oil is connected to the Sea Track Web oil drift model¹. Both IOPAN and IORAS developed models addressing dispersion of CWA: s and conventional munitions.

The IOPAN model, High resolution dispersion model (HRDM), estimates a contaminated area with a 50-meter horizontal with one-hour temporal resolution, and calculates influence of diffusion/advection processes. It is assumed that temperature and salinity do not change during short timescales. It is based on a diffusion-advection equation and uses static downscaling of bottom currents from coarse horizontal resolution model (approx. 2.3 km). This approach gives the possibility for switching into a much higher resolution which is more suitable for assessment of the type of contamination addressed within the DAIMON project. In the model half-life's of CWA: s and their dependence on temperature is also included. The half-life of CWA: s was determined experimentally by PNA in another work package within the DAIMON project. Figure

¹ <http://www.helcom.fi/action-areas/response-to-spills/helcom-seatrackweb-and-oil-drift-modeling/>

2 shows an example of calculated levels of dispersal and contamination after 12 (left graphs) and 36 (right graphs) hours. In the lower two images half-life is considered and in the upper two images half-life is not considered.

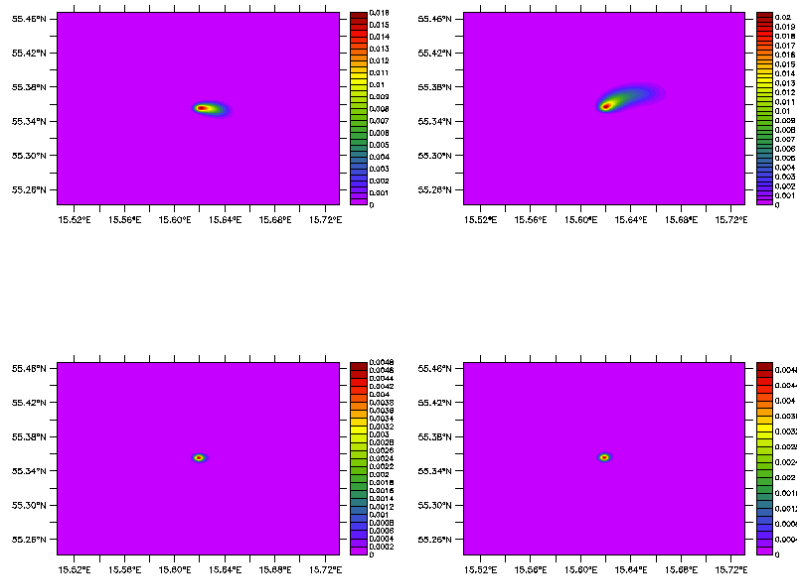


Figure 2. Level of contamination calculated based on HRDM model after 12 (left graphs) and 36 (right graphs) hours. In the lower two images half-life of CWA is considered and in the upper two images half-life of CWA is not considered.

The system consists of two main parts. The first is an operational coupled ice-ocean model for the whole Baltic Sea. The second one is the high-resolution dispersion model, described above, which is connected to the Baltic Sea model through the static downscaling process. The system is operational continuously; it retrieves data from Global Forecasting System, calculates atmospheric conditions for the Baltic Sea area and provides these data to the coupled ice-ocean model. The model performs an integration and the final results are available for the HRDM model.

The system is prepared for providing results of contamination levels via REST API (Representational State Transfer Application) interface, to the DSS (Decision Support System).

Interested parties can send his or her IP number for it to be included in host allows and then granted access to the operational system. Subsequently, based on REST API structure and using 'json' file type it is possible to get results from the system based on 'curl' or a 'wget' command. Connection via REST API, developed during the DAIMON project, to the operational system is established, thus end users are able to get results without any permissions online. The results are provided only in netcdf form.

In the model developed by IORAS they are working on hydrophysical factors that affects the distribution of CWA; 1. Inflows of saline water producing gravity currents, 2. Internal waves that lead to resuspension of sediment and 3. intensification of horizontal pressure gradients.

1. Inflows of saline waters that produce gravity currents in the bottom layer and related transport of tracers (including dissolved and suspended CW by-products) (Fig. 3).

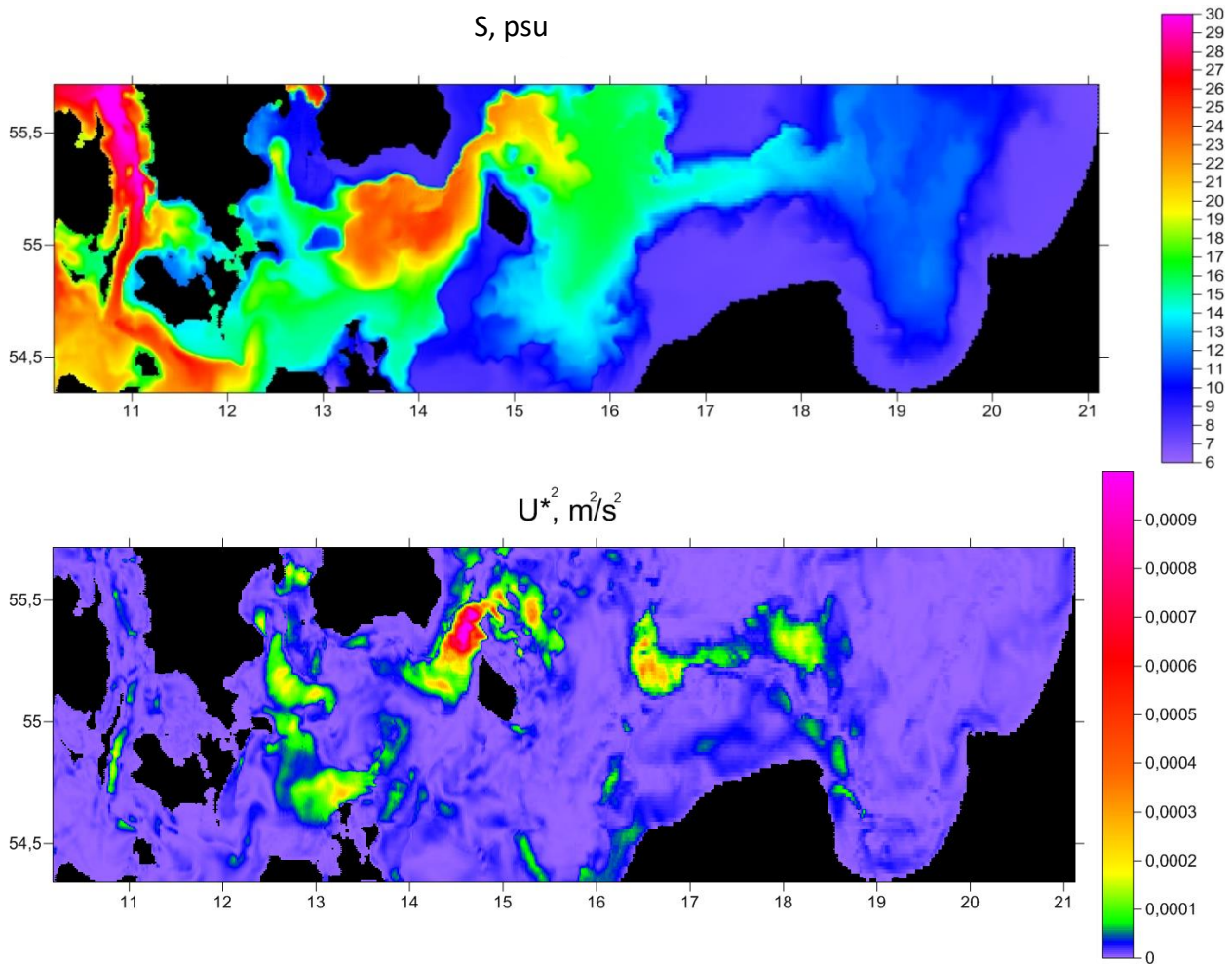


Figure 3. Model distributions of the bottom salinity (top) and squared bottom friction velocity (bottom), illustrating propagation of dense saline waters from the Arkona Basin through the Bornholm Strait into the Bornholm Deep as a gravity current and corresponding increase of the bottom friction velocity. The distributions were constructed from simulation data obtained by M. Golenko and V. Zhurbas in frames of DAIMON project to investigate the influence of inflow events on the bottom friction velocity along the inflow pathway.

2. Internal waves with near-inertial periods develop in deep layers, including the bottom layer, and generate turbulence there, which in turn can lead to resuspension of bottom sediments. And then the weighted material is carried by bottom currents (Fig. 4).

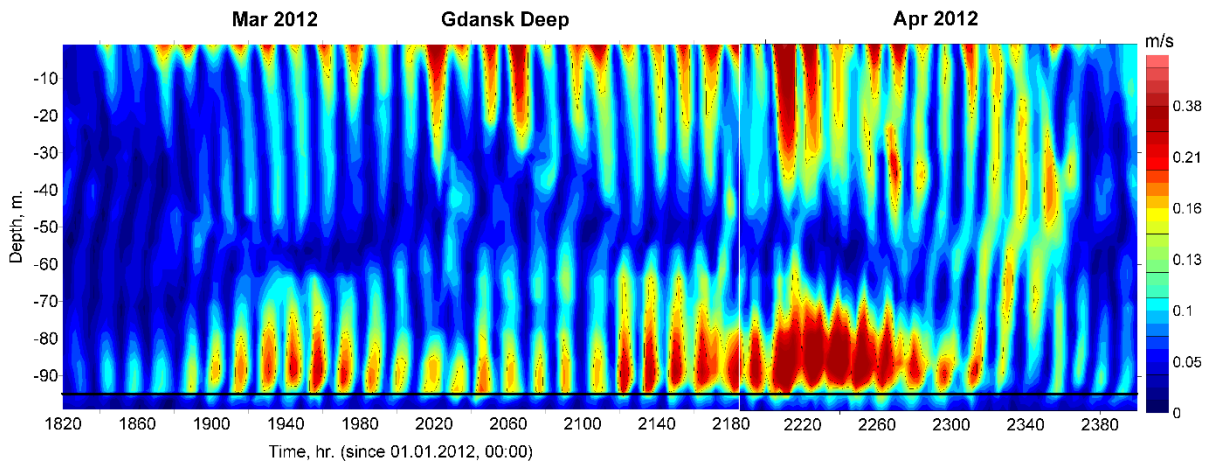


Figure 4. The space-time variability of the horizontal model velocity magnitude in the point situated in the Gdansk dumpsite, illustrating intensification of the near-bottom velocity with near-inertial period (Jakacki et al., 2018)

3. If the sea depth exceeds the Ekman depth and/or there is relatively strong density stratification, the wind forcing is still able to control bottom friction but just indirectly - through the intensification of horizontal pressure gradients due to surges, upwellings/downwellings, generation of internal waves, etc. (Fig. 5).

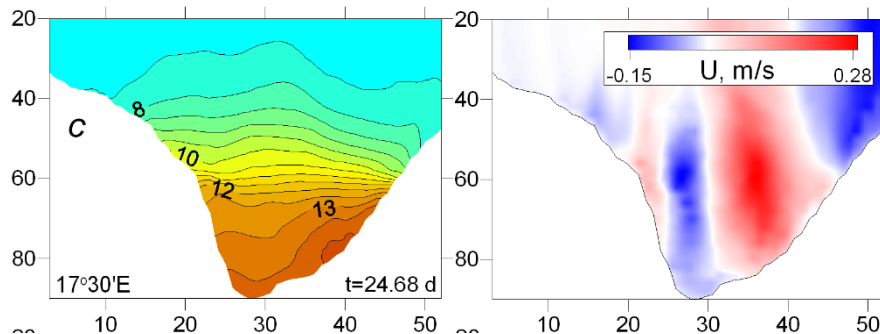


Figure 5. Simulated (left) salinity and (right) along-channel velocity in a cross-section of the Slupsk Furrow, demonstrating the inclination of salinity contours that causes horizontal pressure gradients and corresponding intensification of near-bottom flow (Zhurbas et al., 2012).

2.6.4 Linking of risk chemicals with their possible effects on biota

As ecotoxicological studies using CWA: s entails large difficulties due to CWA toxicity to humans, this kind of studies is scarcely being performed within the DAIMON project or in other projects. Chalmers has for example taken samples for meiofaunal community composition at the Måseskär area, when simultaneously analyzing the sediment for concentrations of CWA. In addition to this study, a literature search has been conducted, to be able to link concentrations of CWA: s with possible effects on biota. However, due to the reasons stated above (human health concern in performing experiments) the potential environmental consequences of

dumped CWA: s to the marine environment are more or less unknown. Low concentrations (0.015 mg/kg) of Yperite (mustard gas) has been shown to induce increased EROD activity in eel (*Anguilla Anguilla*) (Della Torre et al., 2013), and 10 mg/kg had lethal effects (NATO/CCMS, 1995). Yperite has also been shown to have toxic effects in zooplankton (*Daphnia magna*) at 3.3 µg/l in sea water. Similar concentrations of Adamsite and chloroacetophenone had no toxic effects in zooplankton, gastropods or fish (Gorlov, 1993). Otherwise potential environmental effects have been modelled using Quantitative Structure Activity Relationships (qSAR) and Toxic Units (TUs), stating that Triphenylarsine constitutes the highest risk with 0.2 TU, followed by Adamsite 0.17, Clark I 0.086 and yperite at 0.083 TU. Adamsite was also found be the most likely to biomagnify of the investigated CWA compounds (Sanderson et al., 2010).

For most of the chemical warfare agents from the WWI and WWII era, there is an additional aspect that needs to be considered. Arsenic (As) is a component in many CWA: s, such as Lewisite, Adamsite, Clark I and Clark II. Furthermore, Arsine oil contains As, which commonly was added to mustard gas to lower its freezing point (Alcaro et al., 2012; Beldowski et al., 2013; Radke et al., 2014). Roughly one third of the dumped chemical weapons in the Baltic sea is containing As. Inorganic As is both cancerogenic and mutagenic and is far more toxic compared to organoarsenic species, which is common in nature (Duncan et al., 2015; Sanderson et al., 2010). Two forms of inorganic As exists, where As^{3+} is about 60 times more toxic than As^{5+} . Organic species like monomethylarsonic acid (MA) and dimethylarsinic acid (DMA) is then 100 times less toxic than As^{5+} . Under oxic conditions As^{5+} is generally the stable species and As^{3+} under reducing conditions. More complex organic species (e.g. arsenobetaine and arsenosugars) are considered non-toxic (Fauser et al., 2013). Consequently, as CWA compounds eventually will be partly or fully degraded, inorganic arsenic will remain in the marine environment. Degradation products of arsenic-containing CWA: s may also have the same impact on organisms as their toxicity is equal to their precursors and are persistent in the environment (Beldowski et al., 2013; Missiaen et al., 2010). Normally values of As in surface sediments do not exceed 20 µg/g, which is considered as a geochemical background (Beldowski et al., 2013). Hence, concentrations exceeding this in areas with dumped chemical warfare agents can be a good indicator for leakage of chemical munition containing arsenic. Lithium (Li) or Aluminum (Al) can also be used for normalization of As concentrations between areas, as Li and Al are conservative elements (Aloupi 2001; HELCOM 2007). Additional information regarding toxicity of CWA: s can be found in Storgaard et al, 2018.

Thuenen Institute has delivered a threshold table for TNT toxicity (lab) and biomarker responses (field), that is included in the DSS tool (Table 8.). The table contains data from studies carried out by AWI, SYKE and TI-FI. It will in the future also include data on CWA toxicity.

Table 8. Threshold values for TNT toxicity (lab) and biomarker responses (field). Green, yellow and red colors represent thresholds in the DSS tool.

Parameter	Unit	No Effect Level	Effect level 1 cutoff	Effect level 1 Interval low	Effect level 1 Interval high	Effect level 2 cutoff	Effect level 2 Interval low	Effect level 2 Interval high
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2-ADNT Mortality Mac.	mg/l	1	3			> 33		
4-ADNT Mortality Mac.	mg/l	1	3			> 33		
2-ADNT Physiology Mac.	mg/l	0,01	>0,33		3	> 33		
4-ADNT Physiology Mac.	mg/l	0,01	>0,33		3	> 33		
2-ADNT Behaviour Mac.	mg/l	0,01	>0,1		3	> 33		
4-ADNT Behaviour Mac.	mg/l	0,01	>0,1		3	> 33		
TNT Mortality Mac	mg/l	0,01	3			33		
TNT Physiol Mac	mg/l	0,01	>0,33		3			
TNT Behaviour Mac.	mg/l	0,01	>0,33					
TNT Mortality Myt.	mg/L	10				30		
TNT Shell closure Myt.	mg/L	<1.25	>1.25			2,5		
TNT Spawning Myt.	mg/L	0	>0,31			unkno wn		
TNT Accumulation Lipofuscin Myt.	mg/L	<1.25	>1.25			unkno wn		
TNT Accumulation Neutral lipids Myt	mg/L	<1.25	>1.25			unkno wn		
2-ADNT Mortality DR	mg/L	2	>10			> 15		
4-ADNT Mortality DR	mg/L	2	>10			> 15		
TNT Mortality DR	mg/L	0,1	>2			> 4		
2-ADNT Sublethal effects DR	mg/L	1	>7			> 12		
4-ADNT Sublethal effects DR	mg/L	1	>7			> 12		
TNT Sublethal effects DR	mg/L	0,1	>1			> 2		
Catalase activity pos ME	umol/min/mg protein	20	>24			> 28		

Catalase activity neg ME	umol/min/mg protein	20	<16			<12		
Lysosomal membrane stability ME	min	120	>80			> 50		
Acetylcholinesterase activity ME	nmol/min/mg protein	25	>15			> 10		
Fish Disease Index LL	Index value	≤1,55	>1,55			≥5,68		
Macroscopic Liver Neoplasms LL	numeric	0				≥1		
Liver histopathology LL	numeric	0	≥1			≥2		
Hemoglobin LL	mg/dl	≥ 4,82	< 4,82			< 4,02		
Erythrocytes LL	Index value	≥ 0,7025	< 0,7025			< 0,569		
Hematocrit LL	%	≥ 22,4	< 22,4			< 15,6		
Glucose LL	mmol/l	>1,57 ≤ 6,08		> 0,85 ≤ 1,57	> 6,08 ≤ 7,47		< 0,85	>7,47
Fulton's Condition Factor (total weight) LL	numeric	≥ 1	<1			<0,95		
Fish Disease Index GM	Index value	≤0,34	>0,34			≥6,19		
Macroscopic Liver Neoplasms GM	numeric	0				≥1		
Liver histopathology GM	numeric	0	≥1			≥2		
Fulton's Condition Factor (total weight) GM	numeric	≥0,91	<0,91			< 0,85		
Hemoglobin	mg/dl	≥ 5,81	<5,81			<5,06		
Erythrocytes GM	Index value	≥ 0,827	< 0,827			<0,73 6		
Hematocrit GM	%	≥ 33,6	<33,6			<29		

Glucose GM	mmol/l	$\geq 2,49$ $\leq 6,71$		$\geq 0,7 < 2,49$	$> 6,71$ $\leq 9,02$			$< 0,7$	$> 9,02$
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2.6.5. Development of scenarios leading to possible human exposure

There are four primary activities in which humans can be exposed to CWA: s. Through 1/ fisheries, 2/ offshore construction and maritime industry, 3/ tourism and leisure activities, and 4/ through ingestion. IDUM has provided text regarding health impact of dumped munitions and possible scenarios leading to human exposure.

Although it is impossible to predict all the factors involved or the exact circumstances of each individual encounter with underwater chemical munitions or their derivative products, there are several general scenarios in which the likelihood of human exposure increases. These scenarios are based on an analysis of past incidents provided by HELCOM reports and academic publications.

Exposure and Health Impact

Direct or indirect exposure to underwater chemical munitions or their derivative products is most likely to occur when humans use the sea for economic benefit, leisure, or sustenance. However, the risks and hazards vary according to the nature of exposure, the likelihood of contact, and the potential health impact of exposure. It is important to note that most of the risks and hazards associated with underwater munitions remain dormant and potential rather than acute. Exposure occurs by direct or indirect contact with chemical munitions or their derivative products. It can be triggered by munitions fulfilling their intended purposes and detonating or otherwise releasing their toxic contents after being intentionally or unintentionally disturbed. Direct or indirect contact with leaked contents, gaseous vapours, derivative products, or solid chemical warfare agents is more common, particularly if they were accidentally retrieved with other objects (such as fish) or embedded in sediment.

Since chemical weapons were invented for various tactical and operational requirements, their effects on human health can differ. Acute toxic effects can result in short-term incapacitation, mild to severe skin lesions or abrasions, and possible fatality from explosions or interference with the nervous and respiratory systems (HELCOM, 2013). Furthermore, there are also delayed effects from exposure which can materialize over the long-term, either following a single contact or repeated exposure to low concentrations. According to HELCOM 2013 and SIPRI 1975 sub-lethal effects of chemical warfare agents can take the form of “psychopathological-neurological changes, malignant tumours (cancer), increased susceptibility to infectious diseases (primarily of the lungs and upper respiratory tract), disturbances in the liver’s functions, pathological changes in the blood or bone marrow, eye lesions, premature decline in vigour and rapid aging and related functional disturbances such as decline in potency and libido. In addition, most notably for sulfur and nitrogen mustard, mutagenic, teratogenic, and embryonic effects can occur” (HELCOM, 2013; SIPRI, 1975).

Dumping areas were also used to dispose of conventional munitions. Far more numerous than chemical weapons, dumped conventional explosives and ammunition (such as artillery shells or rifle cartridges) are often interspersed in dumpsites and shipwrecks. Exposure to conventional munitions can take the form of two general hazards: energetic and toxicity.

The energetic or explosive hazard is caused by the primary outputs of a detonation: blast pressure, fragmentation, thermal hazards, and shock hazards. Blast pressure is the displacement of air and other gasses caused by the release of energy. Depending the amount of explosive material as well as the duration and proximity of the blast, death or serious damage to the thorax, abdomen, eardrums, and brain can be the result. Fragmentation hazards (such as shrapnel wounds, skin lacerations, and fatality) result from the shattering of an explosive container or secondary fragmentation items released upon detonation. Thermal hazards (such as burns) result from the heat and flame of the explosion. Shock hazards result from the psychological and physiological impacts of a detonation (such as post-traumatic stress disorder [PTSD]).

The toxic hazards of conventional munitions impact human health. Exposure to the chemicals, constituents, and residues from conventional ordnance can pose serious long-term health problems, including cancer. The adverse effects are dependent upon the concentration of chemicals and the pathways by which receptors are exposed. In addition to the chemicals and compounds forming explosives, other toxic materials are present in munitions such as Mercury and Lead.

The severity of the health hazard depends on the toxicity of the substance, size of the dosage, duration, exposure method, and the sensitivity of the surrounding population. Table 9 provides information about conventional munitions and their potential toxic effects.

Table 9. Potential toxic effects from conventional munitions (EPA Review Draft, 2003).

Contaminant	Chemical Composition	Potential Toxicity/Effects
TNT	2,4,6-Trinitrotoluene $C_7H_5N_3O_6$	Possible human carcinogen, targets liver, skin irritations, cataracts.
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine, $C_3H_6N_6O_6$	Possible human carcinogen, prostate problems, nervous system problems, nausea, vomiting. Laboratory exposure to animals indicates potential organ damage.

Contaminant	Chemical Composition	Potential Toxicity/Effects
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine, $C_4H_8N_8O_8$	Animal studies suggest potential liver and central nervous system damage.
PETN	Pentaerythritol tetranitrate $C_5H_8N_4O_{12}$	Irritation to eyes and skin; inhalation causes headaches, weakness, and drop in blood pressure.
Tetryl	2,4,6-Trinitrophenyl-N-methylnitramine, $C_7H_5N_5O_8$	Coughing, fatigue, headaches, eye irritation, lack of appetite, nosebleeds, nausea, and vomiting. The carcinogenicity of tetryl in humans and animals has not been studied.
Picric acid	2,4,6-Trinitrophenol, $C_6H_3N_3O_7$	Headache, vertigo, blood cell damage, gastroenteritis, acute hepatitis, nausea, vomiting, diarrhea, abdominal pain, skin eruptions, and serious dysfunction of the central nervous system.
Explosive D	Ammonium picrate, $C_6H_6N_4O_7$	Moderately irritating to the skin, eyes, and mucous membranes; can produce nausea, vomiting, diarrhea, skin staining, dermatitis, coma, and seizures.
Tetrazene	$C_2H_6N_{10}$	Associated with occupational asthma; irritant and convulsants, hepatotoxin, eye irritation and damage, cardiac depression and low blood pressure, bronchial mucous membrane destruction and pulmonary edema; death.
DEGN	Diethylene glycol dinitrate, $(C_2H_4NO_3)_2O$	Targets the kidneys; nausea, dizziness, and pain in the kidney area. Causes acute renal failure.

Contaminant	Chemical Composition	Potential Toxicity/Effects
Nitrocellulose	Collodion	Intoxicant; impaired motor function, slurred speech, sweating, nausea, vomiting, coma. Possible human carcinogen.
Ammonium nitrate	NH_4NO_3	Prompt fall in blood pressure; roaring sound in the ears with headache and associated vertigo; nausea and vomiting; collapse and coma.
Nitroglycerin (Glycerol trinitrate)	$\text{C}_3\text{H}_5\text{N}_3\text{O}_9$	Eye irritation, potential cardiovascular system effects including blood pressure drop and circulatory collapse.
Lead azide	N_6Pb	Headache, irritability, reduced memory, sleep disturbance, potential kidney and brain damage, anemia.
Lead styphnate	$\text{PbC}_6\text{HN}_3\text{O}_8\text{CH}_2\text{O}$	Widespread organ and systemic effects including central nervous system, immune system, and kidneys. Muscle and joint pains, weakness, risk of high blood pressure, poor appetite, colic, upset stomach, and nausea.
Mercury fulminate	$\text{Hg}(\text{OCN})_2$	Inadequate evidence in humans for carcinogenicity; causes conjunctival irritation and itching; mercury poisoning including chills, swelling of hands, feet, cheeks, and nose followed by loss of hair and ulceration; severe abdominal cramps, bloody diarrhea, corrosive ulceration, bleeding, and necrosis of the gastrointestinal tract; shock and circulatory collapse, and renal failure.
White phosphorus	P_4	Reproductive effects. Liver, heart, or kidney damage; death; skin burns, irritation of throat and lungs, vomiting, stomach cramps, drowsiness.
Perchlorates	ClO_4^-	Exposure causes itching, tearing, and pain; ingestion may cause gastroenteritis with abdominal pain, nausea vomiting, and diarrhea; systemic effects may follow and may include ringing of ears, dizziness, elevated blood

Contaminant	Chemical Composition	Potential Toxicity/Effects
		pressure, blurred vision, and tremors. Chronic effects may include metabolic disorders of the thyroid.
Hydrazine	N_2H_4	Possible human carcinogen; liver, pulmonary, CNS, and respiratory damage; death.
Nitroguanidine	$CH_4N_4O_2$	No human or animal carcinogenicity data available. Specific toxic effects are not documented.

Activities for possible human exposure

Fisheries

Fishermen are the most likely demographic to encounter underwater chemical munitions. The risk is highest when bottom trawling nets are used in or nearby dumping areas, as the nets can dredge the seafloor and catch ordnance along with harvested fish. Although dumping areas are marked on official sea charts and other available navigational information, fishermen might disregard the warnings, operate in unmarked dumpsites, or traverse the debris trails caused by on-route dumping. Fishermen have also relocated munitions over time, such as when they catch munitions in one location and, upon realizing the danger, re-dump the ordnance in another location.

Direct and indirect exposure to chemical weapons is common enough in the Baltic Sea that all fishing vessels are required to carry advanced first aid kits to deal with contamination and all crew members are required to be trained in how to deal with an incident involving underwater munitions. HELCOM tracks the frequency of reported contact with chemical munitions and it has determined that Sulfur mustard-type materials account for 88% of all reported incidents involving fishermen. The frequency of encounters is likely related to the Sulfur mustards low solubility and the fact that its lumps form hard outer shell of intermediate breakdown products in cold sea water (Greenberg et al., 2016). Most instances involving the retrieval of chemical weapons were localized to the Bornholm Basin and some 200 fishermen have sustained injuries requiring medical attention between 1947 and 1992 (Sanderson et al., 2010).

Reported incidents involving chemical munitions were most frequent through the 1980s and peaked in 1990, 1991, and 1992, when 19, 103, and 58 incidents were reported, respectively. With the exception of 2003 when 25 incidents were reported to HELCOM, there has been a notable decline in reported incidents since the early 1990s. The decrease is attributed to the decline of fishing activities in the areas off Bornholm (where the most incidents occurred),

changes in the size of fish population, fewer fishing hours, better fishing technologies, and gaps in national reporting systems (HELCOM, 2013).

Aside from dredging up munitions on trawlers, people working in the fishing industry or in harbours are also at risk of exposure. Two incidents in Sweden highlight an extension to this exposure scenario because munitions can be transported, either intentionally or unintentionally, to more densely populated areas. In April 2011, off the coast of Blekinge, fishermen unknowingly caught a sulfur mustard bomb and transported back to the harbour at Nordersund where they placed it on one of the jetties for emergency personnel to handle. In December 2005, a trawler caught a sea mine and transported it back to Gothenburg and caused part of the port and city to close down. Such events highlight, not only the potential of increasing exposure risks, but it also demonstrates the potential costs to the offshore economy, as contaminated caught fish is required to be destroyed and port facilities might need to be temporarily shut down.

Offshore Construction and Maritime Industry

There is a risk of exposure for those involved in the offshore economy and in the construction industries. Recent economic development related to the exploitation of resources on the seafloor has increased the likelihood of direct and indirect contact with underwater chemical munitions. The experiences documented during the construction of the Nord Stream pipeline (which connected Russian natural gas to Germany via an underwater pipeline) demonstrated that underwater munitions (both inside and outside of dumping areas) represent serious obstacles to infrastructure expansion and the energy sector. The construction of the pipeline required the clearance of over 100 items in Russian, Finnish, Swedish, and German waters (Nord Stream Report, 2010). Construction of offshore wind farms, as well as bridges or any other type of project involving the drilling into the seabed, must account for potential risks of encountering munitions or their toxic substances (CHEMSEA, 2013).

With the increase in activity on the seabed, emergency response personnel and commercial entrepreneurs may see an uptake in the number of times they come into direct or indirect contact with munitions. Poor underwater visibility, differing rates of corrosion, colonization by biota, and the fact that chemical weapons come in a variety of shapes and sizes, make visual identification harder and limit the ability to detect dangers. Accidental contamination from economic activity or in response to an emergency remains a constant possibility.

Project managers in harbours where dumping operations originated (such as in Flensburg or Wolgast) must consider the potential discovery of chemical and conventional munitions in any future harbour development projects. Moreover, the high concentrations of metallic objects in harbour basins can camouflage the presence of munitions. HELCOM recommends approaching construction in ports with comprehensive surveys for munitions, especially in places where dumping is known to have originated. This is especially advised if dredging is required. In 1995, the Finnish Maritime Administration started to expand the port of Kokkola, on Finland's Gulf of Bothnia coast, by expanding the channel and reclaiming land.

Between 1997 and 2001, the depth of the Kokkola channel was increased to 13m, but operations had to be postponed because munitions were found. The Kokkola channel had been used by vessels dumping ordnance between 1945 and 1974. In order for the project to continue, various new safety procedures had to be developed and dredging continued via remote controlled machines (Overview on Underwater Munitions Technology, n.d).

Recent developments in salvage technologies have led to an increasing number of incidents involving undersea piracy. Since 2016 *The Guardian* has reported extensively on events in the Java Sea, in which scavengers locate sunken vessels, detonate charges to break up the ship, and then use cranes and submersibles to recover scrap metals. The costs of this form of marine salvage are justified by the acquisition of low background metals (metals forged before the planet was irradiated by nuclear detonations) (Holmes et al., 2017; Boffey, 2018). Although capital costs, expertise, and other factors (such as depth and composition of shipwrecks) make this recovery scenario less likely overall, it must be stated that cheaper marine technologies and wider knowledge of dumping areas in the Baltic may lead to future recoveries by unlicensed salvage operations or by criminal and terrorist organizations.

Tourism and Leisure Activities

Another demographic at risk of exposure are those people who visit coastal environments for recreational purposes. Many people who visit beaches or engage in leisure pursuits at sea (such as diving) are not aware of the exposure risks. Although the frequency and probability of contact is low, the health consequences of any exposure are severe.

Since most chemical weapons dumped in the Baltic Sea were jettisoned into at least 80 m of water, they are relatively inaccessible to recreational divers or beachcombers. However, because item-by-item dumping was used frequently while on-route to designated dumping areas, unmarked debris trails followed the ship's course. Moreover, items were also liable to float and drift before sinking, which further dispersed munitions outside of designated dumping areas. This opens the possibility of encounters and exposures to munitions along shorelines, particularly as new and technologically-sophisticated diving equipment becomes more readily available and if the ships navigated closer to shorelines while dumping cargo.

The most likely scenario of human exposure to chemical weapons during leisure or tourist activities involves munitions found along shorelines. Young children are the most at risk for accidental exposure, mainly because they are naïve to the dangers and likely to pick up something curious or shiny at the beach. For instance, in July 1955 102 children were injured at a holiday camp in Poland when they played with a rusted barrel (full of liquid sulfur mustard) they found on a beach. At least four children suffered irreversible eye damage as a result (HELCOM, 2013).

Although mustard agents are by far the most reported incidents, they are usually always associated with fishermen. Along shorelines, the most frequently reported cases involve nuggets of white phosphorous, a pyrophoric used in incendiary weapons. White phosphorus can be mistaken for amber and upon drying it can self-ignite and burn up to a 1300°C. In the Baltic, cases

of people being severely burned happen every year, particularly on the German island of Usedom where two to four cases occur every year.

The high concentration of white phosphorus here relates to both post-war dumping operations and the bombing campaigns against the German rocket testing facility at Peenemunde in 1943. According to HELCOM there is approximately 1.2 to 2.5 tons of white phosphorus in the area. Another troubling area is Liepaja beach in Latvia, as the Soviet Union used a dumpsite roughly 70 km from Liepaja (HELCOM, 2013). Incidents involving white phosphorus are not unique to the Baltic Region, as numerous cases along the Dutch and British coastlines have been reported over the years as well (Beddington & Kinloch, 2005).

Ingestion

The highest likelihood of getting into direct contact with chemical warfare materials in the Baltic Sea is through commercial fishing. Consequently, there is also a risk for any fish netted with the warfare materials to be contaminated (e.g., with small lumps of potentially sticky sulfur mustard). When this occurs, the authorities must be alerted, the fishing gear decontaminated and the whole catch destroyed. Some constituents of chemical warfare materials have the potential to biomagnify within the food web. This has been assessed to potentially affect commercially valuable and primarily sediment-active top-predators such as Baltic cod. This species is also of particular concern since the Bornholm dumpsite is located in one of its main breeding areas and offers rich fishing grounds (Niiranen et al., 2008).

No parent chemical warfare agent-associated compounds have been detected in Baltic Sea fish. Based on models results, Sanderson et al. (2009) assessed the maximum recommended monthly amount of fish servings stemming from the primary dumpsites/no-fishing zones in the Bornholm dumpsite to be zero to one. This assessment was based on extreme worst-case assumptions, considering the load of arsenic-containing chemical warfare agents dumped in the area, but not specifically addressing all potential transformation or break-down products. Their study concluded that there was a need for further empirical research, especially regarding the speciation of arsenicals in fish and their carcinogenesis as well as the effects of human exposure to sulfur mustard via seafood.

Studies aiming specifically at the geno-toxicological effects of chemical warfare agents was a target within the CHEMSEA project (chapter 2.3.2.2.2 and De la Torre et al. 2013). The possibility of sulfur mustard poisoning occurring via seafood consumption is supported by newspaper reports stemming from the late 1940s (June 1948, April 1949). It was reported that some Danish and German seafood consumers had become ill after eating fish caught in the area of the Bornholm dumpsite - cod roe later assessed by medical staff was found to contain sulfur mustard (HELCOM 2011a). However, the exposure occurred due to mechanical mixture of warfare compounds with fish roe that was consumed. Bottom-dwelling fish chronically exposed to chemical warfare agents due to their on habitat association in vivo in a dumpsite in the Mediterranean Sea off Bari, Italy, have been shown to carry obvious signs of biomarker responses;

however, no chemical warfare agents were found in the fish flesh and thus any skin diseases, parasite infestation and general low health could be connected to overall environmental stress factors. Further research in this field was recommended by the authors (Della Torre et al., 2013). While no specific analysis for the presence of warfare material constituents is conducted, it is unlikely that seafood showing such signs would go unnoticed in the sorting stage and reach the customer.

Risk calculations and appropriate action for human encounters of munitions

In conjunction with Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, IDUM developed scenarios when underwater munitions can be encountered by humans and the possible actions that can be taken. Different factors such as munition integrity, class of munition, content and amount of munition are considered. IDUM then provided expert judgement input on the scenarios, resulting in a risk level color code from red (most risk) to yellow (medium risk) to green (no action required). The scenarios and results are presented in table 10-11.

Table 10. Risk level calculation according to different scenarios for munitions washed ashore.

Scenario	Munition washed ashore	Munition washed ashore	Munition washed ashore	Munition washed ashore
Munition integrity	3	1	2	2
Risk factor scenario	10	10	10	10
Class	Bomb	Grenade	Bomb	Bomb
Risk factor class	5	2	5	5
Content	Explosives	Tabun	Clark	Unknown
Risk factor content	5	5	4	5
Load (kg)	250	5	20	100
Overall risk	1000	105	420	600
Colour code				
Thresholds	>100	>100	>100	>100
Action	Beach closure, immediate remediation action	Beach closure, immediate remediation action	Beach closure, immediate remediation action	Beach closure, immediate remediation action

Table 11. Risk level calculation according to different scenarios for munitions at seafloor.

Scenario	Munition at seafloor	Munition at seafloor	Munition at seafloor	Munition at seafloor	Munition at seafloor
Munition integrity	3	1	2	3	3
Risk factor scenario	3	2	3	3	3
Class	Bomb	Grenade	Bomb	Grenade	Grenade
Risk factor class	5	2	5	2	2
Content	Explosive	Tabun	Clark	Explosive	Unknown
Risk factor content	3	1	3	3	5
Load	30	3	150	5	10
Overall risk	165	7	240	59	100
Colour code					
Thresholds	>100	<30	>100	31-99	>100
Action	Beach closure, immediate remediation action	No action	Beach closure, immediate remediation action	Monitoring	Beach closure, immediate remediation action

2.6.6. Building a risk categorisation procedure based on the developed lists and scenarios

The decision support system (DSS) developed by TUC are able to include different kind of relevant data in its generic data-source component. Relevant data comes from previous projects, such as Chemsea and data being produced within the DAIMON-project, e.g. sediment characteristics, chemical and conventional munitions dispersal, toxicological data, are of course also included. Other publicly available data, e.g. HELCOM-data, Shark web (Swedish SMHI) is also used. The artificial intelligence system, including a neural network, will then process the data and produce risk categorizations of geographical areas. The AmuCad-system from EGEOS² is then used as a visualization tool for the results (Fig. 6).

If a user wants to risk assess an area in more detail, the assessor will then be able to call on the VRAKA-CWA tool. VRAKA-CWA is a tool for probabilistic estimation of discharge of chemical warfare agents from dumped munitions and the environmental consequences. In the tool the user will be asked to assign; (1) General information, (2) information about Indicators; (3) Volume and type of chemical warfare agent or explosive and (4) Intensity of activities in the area. The probability of the hazardous activities causing an opening in a unit is influenced by a generic probability of an opening in a wreck due to the activity, the intensity of the activity during a year, and several unit- and site specific indicators that influence the state of a specific unit and the probability of an opening. Unit- and site specific indicators are average sea-floor water oxygen concentration, average sea-floor water salinity, average sea-floor water temperature, average sea-floor water current strength, average casing thickness at construction, depth, time since dumping, sea floor character and position of the unit: units are dispersed and lying on the sediment surface, units embedded within the sediment, units inside a wreck, and when units are clustered in a pile of munitions. Activities are construction work, diving, military activity, shipping traffic, storms, trawling, and landslide or sediment settlement.

² <https://www.amucad.org/>

The next part VRAKA-CWA is a consequence assessment approach. The probability of discharge is combined with the volume and toxicity of hazardous substances present in the unit. Finally, using the Bayesian calculations and input variables described above, combined with Monte Carlo simulations of 50 000 iterations risk values and diagrams presenting the results are generated.

The DSS tool only needs the output data from VRAKA-CWA. VRAKA-CWA will be stored and run on a server, at Chalmers University of Technology. In the DSS tool, the URL to VRAKA will be stored. The visualization layer in the DSS then communicates with the Monte Carlo simulations in VRAKA via a defined interface called REST, so the DSS tool can call the Monte Carlo simulation directly. Results are then presented to the user in the EGEOS visualization tool.

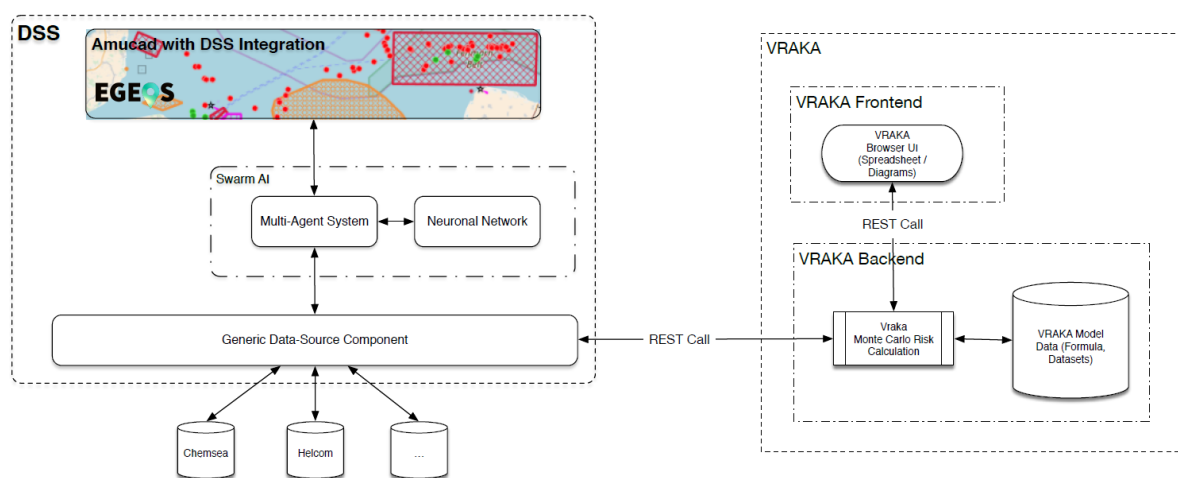


Figure 6. A basic overview of the design of the DSS and VRAKA-CWA tools and the communications between the systems.

2.6 Risk categorization matrix

General description of the DSS

The decision support system (DSS) developed by TUC are able to include different kind of relevant data in its generic data-source component. Relevant data will come from previous projects, such as Chemsea but data being produced within the DAIMON-project, e.g. sediment characteristics, chemical and conventional munitions dispersal, toxicological data, are of course also included. Other publicly available data, e.g. HELCOM-data, Shark web (Swedish SMHI) is also used. The artificial intelligence system, including a neural network, will then process the data and produce risk categorizations of geographical areas. The Amucad from EGEOS is then used as a visualization tool for the results.

General description of VRAKA-CWA

VRAKA-CWA is a tool for probabilistic estimation of discharge of chemical warfare agents from dumped munitions and the environmental consequences. In the tool the user will be asked to assign; (1) General information, (2) information about Indicators; (3) Volume and type of

chemical warfare agent or explosive and (4) Intensity of activities in the area. The probability of the hazardous activities causing an opening in a unit is influenced by a generic probability of an opening in a wreck due to the activity, the intensity of the activity during a year, and a number of unit- and site-specific indicators that influence the state of a specific unit and the probability of an opening. Unit- and site-specific indicators are average sea-floor water oxygen concentration, average sea-floor water salinity, average sea-floor water temperature, average sea-floor water current strength, average casing thickness at construction, depth, time since dumping, sea floor character and position of the unit: units are dispersed and lying on the sediment surface, units embedded within the sediment, units inside a wreck, and when units are clustered in a pile of munitions. Activities are construction work, diving, military activity, shipping traffic, storms, trawling, and landslide or sediment settlement.

The next part VRAKA-CWA is a consequence assessment approach. The probability of discharge is combined with the volume and toxicity of hazardous substances present in the unit. Finally, using the Bayesian calculations and input variables described above, combined with Monte Carlo simulations of 50 000 iterations risk values and diagrams presenting the results are generated.

Combination of the two tools

The DSS tool can provide an initial risk assessment of a wider area. If a user wants to risk assess an area in more detail, the assessor will then be able to call on the VRAKA-CWA tool. The DSS tool only needs the output data from VRAKA-CWA. VRAKA-CWA will be stored and run on a server, at Chalmers University of Technology. In the DSS tool, the URL to VRAKA will be stored. The visualization layer in the DSS then communicates with the Monte Carlo simulations in VRAKA via a defined interface called REST, so the DSS tool can call the Monte-Carlo simulation directly. Results are then presented to the user in the EGEOS visualization tool.

Translation of parameters to risk

Within the decision support system (DSS) there are a number of parameters that are included, where they represent for example risk levels, concentrations of chemicals, rate of corrosion or dispersal. For the DSS system to be able to assess the total risk at a geographical area the partners within the DAIMON needs to translate the parameters to a risk, divided into five different risk categories. All project partners performed this task within the project.

Organizations/Institutions using the main output

There are groups of organizations and institutions around the Baltic Sea and worldwide, besides DAIMON project partners, that would in the future like to use the risk categorisation matrix. They could then use it to translate results of ecotoxicological studies, concentrations of CWA in biota and sediment at CWA and conventional munition dumping sites into risk levels.

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