First scientific support plan for a sustainable development policy (SPSD I)

Programme "Sustainable management of the North Sea"

EVALUATION OF THE "PAARDENMARKT" SITE

Summary of the research

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SUMMARY

INTRODUCTION

After the first World War a considerable amount of war material was dumped on a shallow sand flat called “Paardenmarkt”, offshore Knokke-Heist, Belgium. The dump site extends over 3 km^2, and is indicated on hydrographic maps with a pentagon where neither fishing nor anchoring is allowed.

Geophysical investigations in 1995-1996 showed the extreme complexity of the area, not only related to the dumped material (partly non-metallic, and thus “invisible” for magnetic methods) but also in relation to the natural settings and the (recent) evolution of the site.

Although these first results showed that a combination of acoustic and magnetic methods is very effective, it was clear that complementary research techniques were necessary to analyse the full complexity of the Paardenmarkt in all its facets. This should allow to evaluate the possible risks for the environment and the population which might be directly exposed to this environment, including the users of the sea.

GOALS OF THE PROJECT

Correct evaluation of the present situation of the dump site requires an integrated multi-disciplinary scientific approach. Consequently, the principal objective of this study was to combine geophysical, geochemical, sediment-dynamical, biological, engineering and ecological expertise.

The main objectives of the Paardenmarkt site evaluation project included the following:

- Detailed analysis and scientific evaluation of all available data related to the area, in order to make a correct evaluation of the actual dimension of the encountered problems.
- Analysis of possible strategies of scientific research with respect to the dumped munition and natural setting, and the possible perspectives for continuous monitoring of the area.
- Re-evaluation of the present-day ‘status quo’ policy and the evaluation of different options for possible engineering solutions, including a nature conservation area.
- Evaluation of possible strategies related to communication and information transfer in order to meet public concern, and further expansion of the international dimension.

In order to meet these goals the study was structured in 7 main research themes : (1) Synthesis of the available historical and recent data; (2) Evaluation strategy of the dump site; (3) Strategy for the evaluation of agent / gas behaviour; (4) Perspectives for monitoring of the dump site; (5) Re-evaluation of the present policy and potential for rehabilitation of the site; (6) Communication and public information; (7) International capacity building.

In total 8 research teams were involved in the study : (1) Renard Centre of Marine Geology (RCMG), Gent University (coordinator); (2) Consulting office MAGELAS; (3) Consulting office G-TEC; (4) TNO-Prins Maurits Laboratory (NL); (5) CEREGE-University of Aix-Marseille (F); (6) Marine Biology Department, Gent University; (7) Civil Engineering Department, Gent University; (8) Institute of Nature Conservation.

RESULTS OF THE STUDY

1. Synthesis of the available historical and recent data

History of the Paardenmarkt site

- The total amount of dumped warfare is estimated to be 35.000 tons. Most likely it involves German ammunition, mainly 77mm shells. Probably roughly one third of the munition is toxic, most likely filled with (di)phosgene, chloropicrin, Clark or Yperite (mustard gas).
- Newspaper articles and parliamentary records from 1919 suggest the possibility of a second, British dumping operation. So far there is no firm proof of this operation.
- Diving operations in 1972 reveal the presence of munition on the sea floor. The area is marked on hydrographic maps as "no anchorage or fishing zone". Based on magnetometric results from 1988 this (rectangular) delimitation zone is finally enlarged to a pentagon with a total surface of ± 3 km^2.

Recent geophysical / geochemical research

- Geophysical investigations carried out in 1995-1996 indicate a highly complex area (high sediment input, natural gas, magnetic and non-magnetic material).
- Magnetometric data indicate a central zone with large magnetic anomalies, representing the main part of the dumped munition, surrounded by a wide zone with various weaker anomalies. The munition in the central zone seems to be completely buried under a few meters of sediment.
- Sediment and water samples taken at the site in 1995-1997 do not indicate contamination, except for one sample showing a low concentration of Yperite. Additional sampling in the vicinity cannot confirm this.
- An integrated geophysical and sampling campaign was carried out in the fall of 2000 to study the Paardenmarkt site in a broader sediment dynamical framework.

Sedimentary processes and dynamics

- The water depth at the site varies between 5.6 and 1.5 m MLLWS. Tidal currents are mainly rectilinear, oriented NE-SW, with max. values of ~1.50 m/s. Main winds & storm waves are SSW-SW resp. NW oriented.
- The surficial sediments are sandy and muddy. Influence is likely from the nearby dumping ground of dredged material (mixture of sand and mud).
- The dump site is located in a turbidity maximum area hydraulically trapping the muddy deposits. Residual transport directions based on sediment variations indicate a coastward transport near the munition dump site.
- Between 1954 and 1976 a section of the dump site was subject to erosion. This explains why Navy divers in 1972 were able to observe munition on the sea floor.
- Extension of the Zeebrugge harbour induced an explicit sedimentation at the dump site (up to 4 m in the SW corner, decreasing towards the north) and an erosion zone NW of the site.
- Recent data seem to suggest a slow migration of this erosion zone towards the east and a trend towards stagnation in the sedimentation/erosion process, but further verification is still needed.

Similar research in other countries

- At least 80 chemical and conventional munition dump sites have been identified in the North Sea and North-East Atlantic (excluding the Baltic Sea). However this list may well be incomplete.
- Despite the research carried out over the last decades a great number of questions and uncertainties still exist. Very little is known about the migration of toxic agents in the marine environment (water & sediments) and their impact on this environment.
- International reports stress the following needs: inventarisation, in-situ investigations, fundamental research, risk modelling, public openness, emergency planning, and international collaboration.

2. Evaluation strategy of the dump site

Potential of 3D VHR geophysical methods

- Important improvements in 3D seismic & magnetic technology (including simultaneous use) will allow further improvement of the spatial characterisation of the munition and surrounding sediments.
- Novel 4-component bottom cable methodologies offer wide perspectives for the detailed characterisation of sediment properties and migration pathways.
- Self-potential surveys can provide valuable information for the location of metallic objects in shallow sediments; this method is cheap and easy to use.

Potential of sediment dynamic research

- Bathymetrical investigations can best be carried out with a multibeam echosounder system allowing a quantitative highly accurate and full-coverage monitoring of the seabed topography.
- Morphological research can be based on multibeam and/or side-scan sonar data. Both methods permit a qualitative analysis of sediment transport and acoustical seafloor characterisation.
- Hydrodynamic and sediment dynamic information can be obtained using an Acoustic Doppler Current Profiler (AcDCP) in combination with Optical BackScatter sensors (OBS).

Biological benthos research

- The recent changes within the sedimentology and bathymetry of the dump site may have caused an alteration within the benthos. However no benthos data are available to test this hypothesis.
- The benthos of the eastern coastal zone is poor compared to the western coastal zone. The dump site is marked by the dominance of a very impoverished type of the *Abra alba - Mysella bidentata* community.
- The presence of biogenic gas might locally enhance benthic productivity. However, the effects on the benthic community structure is not known.

3. Strategy for the evaluation of agent / gas behaviour

General chemical background

- Due to the large dilution involved and the relative fast hydrolysis most chemical warfare agents will probably not pose an important threat to the marine environment. The main threats are related to Clark and Yperite.
- Due to their slow hydrolysis and equally toxic breakdown products both Clark I and Clark II may form a long-lasting threat to the marine environment.
- Due to its extremely slow hydrolysis (it can persist for decades or longer) Yperite may form a long-lasting threat to the marine environment.
- Due to the large quantities involved TNT (explosives) could possibly pose a threat to the marine environment.

Potential of (gas) migration research

- The (methane) gas in the mud-rich sediments is most likely of biogenic origin, related to the presence of a thin peat-rich layer. Seismic data suggest a low concentration of gas, probably < 1%.
- The gas bubbles have little influence on the electrical and thermal conductivity. The sediment compressibility will increase linear with the gas content; viscosity depends on a power law with the gas content.
- The likely sediment volume that could be affected by released (lumps of) Yperite will depend on the dissolution rate and the interstitial diffusion. In general the affected radius will be very small (< 30 cm).

Long-term behaviour and ecotoxicological aspects

- The long-term behaviour and detoxification of toxic warfare agents in the marine environment is largely determined by their solubility in sea water.
- The main threat of Yperite is related to direct contact with organisms.
- Clark compounds will easily adsorb onto sediments and may therefore pose a long-lasting burden to marine organisms living on the sea floor.
- Most likely TNT will not pose a major ecotoxicological threat at the Paardenmarkt; it also seems unlikely that high concentrations of DNT may be expected in the marine environment.
- Heavy metals do not degrade and may form a long-lasting environmental burden. Due to the large dilution their concentration in the water column will be rather low; still peak concentrations cannot be excluded (in the sediments) near the munition.
- Further research is needed to study the chronic and sub-lethal effects on the marine environment and toxicological effects of organisms living and feeding on the sediment.

4. Perspectives for monitoring of the dump site

Strategy for geophysical monitoring

- Monitoring of the sea bed is crucial as it allows to map the evolution in erosion/accumulation of the area and detect objects on the sea floor. A survey interval of one year seems appropriate in the starting phase.
- Additional depth monitoring of the dump site is needed to map its internal structure and its evolution. A survey interval of 3 to 5 years seems appropriate in the starting phase.
- Because of the limited water depth a survey vessel with little draught is needed. This will

limit the number of different sensors and data acquisition systems that can be operated.

- The development of a "Paardenmarkt observatory" is proposed in order to allow optimum management of monitoring and the advancement of fundamental insight.
- In the case of an artificial island internal depth monitoring can be one using horizontal or vertical boreholes; a monitoring interval of 5-10 years seems appropriate.
- In the case of munition recovery geophysical monitoring of the highest possible resolution is essential before and during the recovery operations.

Strategy for geochemical monitoring

- Thorough geochemical monitoring is of the utmost importance and should be started with priority; it will allow to gain information on the state of the degeneration process.
- Sampling should be done at fixed positions and set intervals, using the same protocol. A monitoring interval of one year seems appropriate in the starting phase.
- Sediment and water samples should also be taken in the surrounding area for reference.
- Specific screening should be done for munition-related heavy metals, TNT, Yperite, Clark, and their respective breakdown products.
- In view of the extreme proximity of the coast it may be useful to keep a chemical watch (e.g. chemical sensors) between the dump site and the beach.
- In the case of an artificial island geochemical sampling should focus on the border area. Additional chemical monitoring in boreholes (equipped with a water filters) is possible.
- Munition recovery may cause the release of uncontrolled amounts of toxic agents; detailed geochemical monitoring should therefore be carried out throughout the entire operation.

Strategy for biological monitoring

- Monitoring of sea- and coastal birds should be done on regular intervals using different techniques (ship, airplane, counts from land) with additional information from surveys at the coastline.
- The infauna can be monitored in relation to a reference site or using known benthos-sediment relationships (HABITAT-model). Sampling should involve hand-operated cores in order to reduce risks to a minimum.
- Bioaccumulation of chemical compounds in benthic invertebrates can be used as a monitoring tool for munition leakage.
- In the case of an artificial island biological monitoring should include breeding colonial seabirds, biological/ecotoxicological parameters, vegetation structure, and benthic colonisation.

5. Re-evaluation of the present policy and potential for rehabilitation of the site

Risk analysis of the present situation

- Most likely the munition is not yet too heavily corroded. The oxygen-poor conditions related to the presence of biogenic gas are expected to slow down the corrosion process. It could take hundreds of years, possibly 1000 years, before all of the munition has corroded completely.
- Upon corrosion the chemical compounds will be released very slowly. Peak concentrations may happen in case of mechanical disturbance (anchoring, fishing, recovery operations).

- Clark may cause long-lasting contamination of the sediments, threatening the organisms living near or in the bottom. In general the threat will be local and therefore rather limited, although a larger contamination radius is possible through sea-floor erosion.
- Being a viscous liquid Yperite is expected to largely remain in the shell after corrosion of the munition. Due to mechanical disturbance lumps may be released, which could possibly reach the shore.
- The risk of large-scale shipping disasters (e.g. due to storms) has to be considered. Fishing or construction incidents cannot be ruled out, but are more likely to involve dispersed munition outside the dump site area.
- Attention should be paid to the long-term effects of global warming and sea-level rise. Global warming will enhance the storm frequency, thus increasing the risk for shipping disasters. Sea-level rise could result in salt water intrusion due to an induced groundwater flux from sea to land, causing a long-term effect on enhanced pollutants pathways.
- Washing ashore of munition shells is not very likely to happen but cannot be excluded completely.
- The threat to human health related to the consumption of contaminated fish is very small.
- Further extension of the erosion zone NW of dump site towards the south-east could result in erosion of (part of) the dump site, and cause the munition to surface. Close monitoring of this zone is therefore crucial.
- In order to better assess the current and future risks of the dump site further research and in-situ investigations are necessary (recovery of a number of shells, sampling, sediment dynamic investigations).

Evaluation of possible engineering options

- Different options to cover the dump site include sand suppletion, detached breakwater and an artificial island. The latter seems most favourable regarding durability and added ecological value.
- An artificial island used as possible breeding place requires to fill up the site to a level of Z+6.50 m. A "horseshoe" structure is preferred: 3 sides formed by a rubble mound structure, 2 sides by a sand slope.
- The total cost price of the island construction is estimated at 405 million EURO (16.4 billion BEF), TAV not included. This is a rough estimate and can be influenced by a range of factors.
- The construction of an island does not totally solve the long-term environmental threat of the leaking agents, and monitoring will therefore still be needed.
- Munition recovery seems feasible with the present technology, but will require detailed preliminary studies. A minimum duration of 2 to 3 years seems realistic. Preliminary estimations of the total costs range from ten million EURO up to hundreds of millions EURO.
- Any recovery operation will involve high risks both for salvage crews and for the environment, and demands adequate transport. Destruction of the recovered munition will pose a major problem. Unless acute danger is involved recovery is therefore not considered to be the best solution.

Potential rehabilitation into a nature conservation area

- The construction of an island offers major opportunities as a nesting site for terns, gulls and plovers and a roosting site for seals. It would ensure the continued existence of terns and gulls which are now doomed to disappear due to increasing harbour development. Specific (ecological) conditions must be met in order to offer suitable breeding habitats.
- The intertidal biota of the island will provide feeding grounds for breeding as well as migrating and wintering birds. The absence of human disturbance and the creation of numerous microhabitats will likely produce an increase of hard substrate biodiversity.

6. Communication and public information

- In order to create more openness towards the public an information brochure will be published in the near future (in close collaboration with MUMM).
- Additional steps towards communication and public information include the publication of specialist and non-specialist articles (scientific journals, VLIZ magazine), publication of the workshop proceedings, European dump site inventory (preparatory phase).

7. International capacity building

Organisation of an international workshop

- An international workshop on "Chemical munition dump sites in coastal environments" was held in Gent (July 2001). Its main goal was to provide an overview of the research and national policy in Europe.
- The main conclusions of the workshop stressed the need for (1) more research to assess the correct status of dump sites, (2) a uniform standard in risk assessment (development of risk model), and (3) inventory of European marine munition dump sites.

Exploring the European dimension

- In February 2000 the TOXDUMP proposal was submitted. Though reviewed positively the project was not accepted for funding. A new proposal will be prepared for the EU 6th framework programme.
- In October 2000 RCMG and TNO participated in the NATO Seminar on "Environmental and safety implications of dumped ordnance in coastal waters".
- In collaboration with Forschungszentrum Terramare (Germany) a geophysical survey was carried out with RV Belgica on munition dump sites in the Wadden Sea (Oct. 2001).
- The capacity of the new VHR 3D seismic method will be demonstrated during a field workshop in 2003.

Strategy for the dissemination of expertise

- Publication of the workshop proceedings is scheduled for winter 2001/2002.
- First steps have been taken towards an inventory of European marine CW dump sites.
- Technological results of the Paardenmarkt study are currently being published.

RECOMMENDATIONS FOR FUTURE POLICY AND RESEARCH

At this moment a large number of factors remain unknown. In order to allow a correct evaluation of the dump site in-situ measurements and monitoring are indispensable.

In order to evaluate the actual condition of the munition and their state of corrosion, it is necessary to recover a (representative) number of shells. The recovered munition can be used to model the degradation process.

It is of the utmost importance to set up a regular monitoring programme as soon as possible. Geochemical sampling should be started with high priority. The analysis of water and soil samples can give information on the actual state of potential leakage and detoxification processes. Additional biological assays should be carried out in order to verify the degree of ecological damage.

Sea bed monitoring is crucial to map the erosion/accumulation processes and detect possible objects on the sea floor. Particular attention should be paid to the erosion zone NW of the dump site. Further extension of this zone towards the south-east (possible connection with the Appelzak swale) could result in erosion at (part of) the dump site, eventually causing munition to become exposed on the sea bed. Additional in-depth monitoring is needed to map the internal structure of the dump site and its evolution.

One of the main problems of the Paardenmarkt is its close proximity to the coast. Although it is unlikely that munition shells may be easily displaced, the chance for Yperite lumps to reach the shore cannot be ruled out entirely. Therefore it may be useful to keep a chemical watch (e.g. chemical sensors) between the dump site and the beach as a basic safety measure.

In order to guarantee an optimal long-term monitoring strategy of the dump site the development of a "Paardenmarkt observatory" is proposed. The latter will not only deal with management of monitoring and the advancement of fundamental insight, but can also adequately support a strategy for communication. *Mutatis mutandis*, the concept is inspired by e.g. the "Observatoires du littoral" in France, however with a much more focused mandate.

Together with the in-situ data and monitoring further fundamental research is needed. Important knowledge gaps include the dynamical behaviour of toxic agents, their long-term environmental effects (also on seafloor-related organisms), the simultaneous use of survey techniques, risk assessment modelling. Such research should happen both through national projects and international collaboration.

At this moment there do not seem to be strong indications for acute danger. The best option therefore seems to be to leave the dump site untouched - under the condition of regular monitoring. The latter is needed to track the evolution of the site and to detect any possible hazards in the future.

If monitoring would indicate potential surfacing of the munition (due to erosion of the sediment cover) the construction of an artificial island should be seriously considered. In doing so specific ecological conditions will have to be met to allow optimum use as a nesting and roosting site.

However such protection and reclamation does not totally solve the long-term environmental threat of the leaking agents, and monitoring will therefore still be needed.

Total recovery of the dumped munition is in theory the only way to solve the problem at heart. However this will be a costly and highly risky operation, and may cause the release of unverifiable amounts of toxic compounds into the environment. Moreover, it requires an extensive dismantling capacity, and adequate transport. Unless there is acute danger involved recovery is therefore not considered to be the best solution.

Attention should be paid to the long-term effects of global warming and sea-level rise. Global warming will enhance the storm frequency, thus increasing the risk for (large-scale) shipping disasters at the dump site, while sea-level rise may induce groundwater flux from sea to land, with the enhanced risk of coastal aquifer pollution.

Creating more openness and public awareness is very important. Not only will this help to take away the incertitude and doubts on the subject, but it will also avoid over-concerned reactions.

Last but not least, it is clear that no strategic reflection can outstrip the ethical motives and common sense involved. This problem deserves the best of our capacities, both today and in times to come. This we owe to society and the future generations.