SAFETY AT SEA

Marine Environmental Risk Assessment System:

Conceptual design and preliminary demonstration for the Dutch Continental Shelf.

Demo A: Inventory, classification and risk assessment
of oil transport on the North Sea
Report No A11 > Revision No 1> 2007-05-03
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Executive Summary

Maritime safety is a crucial issue on the international agenda and specifically in the North Sea due to the increasing traffic, recent accidents and new developments within offshore wind farms. In order to face the challenges in a trans-national perspective, the Safety at Sea project was established and kicked-off in 2004, due to finish in 2007. Within the Safety at Sea project a number of demonstration projects are defined. This report is part of the demo project A: Inventory, classification and risk assessment of oil transport in the Interreg IIIB North Sea region. It presents the results of activity A11 of Demo A: “Identify Marine Environmental High Risk Areas (MEHRA’s)”. This work was carried out in collaboration with SINTEF (Norway). The objective of this study is to develop a methodology and tool for an Environmental Risk Assessment for oil (and other chemical) spills.

Results of two of the other demonstration projects in Demo A were used directly in Activity A11 to generate spatial risk maps. In activity A6 of Demo A, which was carried out by MARIN (“Risk study on the Outflow of Oil on the Dutch Part of the North Sea”), oil spill probabilities due to shipping incidents are derived for a number of oil types and 8 spill size classes for each oil type. A second study, Activity A9, carried out by RIKZ and Alterra (“An integrated approach to map ecologically vulnerable areas in marine waters in the Netherlands (V-maps)”) generated Ecological Vulnerability maps for the Dutch Continental Shelf.

Risk is defined as a combination of the probability of an event and the consequences of the event. The consequences are the result of exposure, E, and vulnerability, V. The vulnerability is expressed by Vulnerability Maps. The exposure can be described by numerous indicators, such as duration of the exposure, concentration, type of substance(s) etc. or by a combination of these factors. To generate spatial risk maps in this study, a novel methodology is developed and applied, in which stochastic simulations using a particle-tracking transport model (DELFT3D-PART) are used. The particle-tracking model is driven by historical wind series that are sampled from a 54 year long record (1952-2006). The stochastic wind data sets have been selected to represent annual average conditions as well as seasonal conditions. The observed wind record was obtained from the Royal Dutch Meteorological Office (KNMI).

Input to the stochastic model is specified by the spatially distributed spill probabilities that are generated by MARIN. The result of the stochastic particle-tracking model is an oil presence probability map, representing the probability that oil is present due to an oil spill from a shipping incident. In this demonstration project the horizontal transport behaviour of oil is modelled. Oil processes that affect the fate of spilled oil are not included in the modelling at this stage of the project. For two oil types (a heavy and a medium crude oil) stochastic modelling has been carried out and maps have been generated for 8 oil spill size classes for each of the two oil types.

The risk maps are generated by combining the oil presence probability maps and the vulnerability maps as generated by RIKZ and Alterra. There are many ways by which this can be done, but a few principles have formed the basis for the link.

- The higher the oil presence probability with a constant vulnerability, the larger the environmental risk;
- The more vulnerable the area with the same oil presence probability, the larger the risk;
- The larger the spill volume, the larger the environmental damage, because a larger spill will cover a larger area and will have a greater impact.

For two oil types and two representative 2-month periods, risk maps have been generated. The relative distribution of the risks provide an indication for the definition of Marine Environmental High Risk Areas, and as an example, maps have been generated that indicate 10% of the total area representing the highest risk within the Dutch Continental Shelf. This area is located around the entrance of Rotterdam harbour showing the dominating effect of the high traffic density and resulting relative high oil spill probabilities.

For two types of oil the methodology was demonstrated successfully. It is recognised that the work presented in this report represents a first step in the development of an European wide consistent methodology and the development of a European wide tool for assessing environmental risk due to shipping incidents. Recommendations for further work have been presented in the report.

1 Introduction and purpose of the study

1.1 Background

Maritime safety is a crucial issue on the international agenda and specifically in the North Sea due to the increasing traffic, recent accidents and new developments within offshore wind farms. In order to face the challenges in a trans-national perspective, the Safety at Sea project was established and kicked-off in 2004, due to finish in 2007.

The Safety at Sea (S@S) project is an EU Interreg IIIB North Sea project, managed by the Norwegian Coastal Administration. The objective of the project is formulated as: “To stimulate the national, regional and local governments to cooperate to find common strategies and best available practices to reduce the risk and impact of accidents in the North Sea”.

Some of the results expected from the project are:

- An updated risk assessment of oil transport in the North Sea region;
- New and innovative use of AIS technology to improve navigation;
- Improved procedures for oil spill preparedness;
- Risk assessment of forecasted offshore wind farms;
- Improved decision support for marine rescue coordination centres;
- Increased knowledge about safety measures for small and high speed crafts in the North Sea.

The project is co-financed by the European Community and has a total budget of about 5 million euros. The 3-year project was officially kicked off in September 2004. The project will result in a policy paper containing recommendations on harmonisation of best practice safety measures in the countries around the North Sea. Within the S@S project a number of demonstration projects are defined. This report is part of the demo project A: Inventory, classification and risk assessment of oil transport in the Interreg IIIB North Sea region.

This report presents the results of activity A11 of Demo A: “Identify Marine Environmental High Risk Areas (MEHRA’s)”. This study was commissioned by the Ministry of Transport, Public Works and Water Management, Directorate-General of Public Works and Water Management National Institute for Coastal and Marine Management (RIKZ) and carried out by WL | Delft Hydraulics in close discussion with SINTEF.

1.2 Objective

A European wide systematic approach for a marine environmental risk assessment for potential oil (and other chemicals) spills from shipping accidents does not exist. Within the European Union waters, individual countries apply different approaches and techniques to assess environmental risk. As a result comparisons of the results of these assessments cannot be carried out thus preventing a consistent European wide overview of environmental risk. A European wide consistent methodology is required to assess areas of priority and to develop strategies to minimise these risks. If this methodology would be applied throughout the European waters, then a consistent European wide Marine Environmental Risk map would become feasible. Based on such a map, Marine Environmental High Risk Areas (MEHRA’s) can be assigned on a European scale. Such a European wide risk map can also form the basis for the development of contingency planning on a European scale, which contributes to and promotes international collaboration.

Therefore, the aim of this study is to develop a methodology and tool for an Environmental Risk Assessment for oil (and other chemical) spills.

In this study, as part of the Safety at Sea project, the development of the risk map is restricted to a demonstration of techniques to generate risk maps. A demonstration is carried out of the feasibility of the methodology using tools that are presently available.

In the first instance the risk map focuses on oil spills, but can be extended, using a similar methodology, to other type of (accidental) spills.

Since the final objective is to provide a (ultimately European wide) tool for assessing environmental risk due to shipping incidents, an outline of such a tool will be given first. The development of such a tool is, however, not possible within the constraints of the Safety at Sea project. So once a description of the outline is given, a demonstration of the feasibility of the tool is carried out using tools that have already been developed and may form part of the final risk assessment tool. In this project, the tool will focus on oil spills, but should eventually also be suitable to handle other types of substances, such as chemicals.

2 Conceptual design of a (oil) risk tool

2.1 Background

An environmental risk map is defined as a combination of the probability of an event (presence of oil) and the damage the event causes (to the environment). In this case the event is an accidental oil spill at sea and the environment is represented by the marine ecology. The probability of accidental oil spills can be described spatially, such as throughout European Waters. The impact of such spills can be simulated with computational models. Sensitivity of the ecology to presence of oil can be described by vulnerability maps (V-maps, Offringa and Lahr, 2006). The V-maps indicate which areas are more vulnerable to a spill of a particular substance (e.g. oil type) than others. The degree of vulnerability is dependent on the potential damage, but also the expected recovery of the selected ecosystem components present in that area.

At present there are two main approaches that derive the probability of oil pollution from spills:

1. The first method, developed at WL | Delft Hydraulics (Kleissen, 2004), uses the spatial probability of oil releases from shipping accidents (as derived by Koldenhof and Bolt, 2007), without focussing on particular locations and local environmental conditions, as an input to their pollution transport model. The method uses stochastically derived wind forcing and average hydrodynamics. The results of the modelling are spatial probability maps of oil presence and coastal pollution (P-maps). This computationally efficient approach provides the information to derive general risk maps.
2. The second method, which was developed at SINTEF (Skognes and Johansen, 2004) but is also used elsewhere, is to generate a long time-record of hydrodynamic conditions (output files from hydrodynamic models with actual historical forcing). Within an oil model, oil is then released from specific locations and at random times (or periods). The model provides an estimate of the spatial probability of the presence of oil and coastal oil pollution, given a release from these locations. Here, the fate of the spilled oil is also modelled, and includes a large number of oil processes, such as entrainment of oil in water, evaporation, emusification, etc. This method is particularly suitable when focussing on a limited number of possible spill locations and can be regarded as providing the information to generate specific risk maps.

The full risk assessment tool should combine both methods, since the spatial probability method (1) provides the means to focus on areas that have the highest levels of risk. Then the specific probability method (2) can be used to investigate these high risk areas in more detail, including descriptions of the fate of oil and spill response options. Both approaches take account of climatic conditions and make use of historical meteorological forcing. Hence, the results provide an insight of long term probability distribution of pollution due to accidental releases at sea.

2.2 General requirements of the risk tool

If a full risk assessment tool is to be developed, and able to meet the general objectives, then a minimum set of requirements need to be defined.

- The system needs to be able to accept different oil types, because the shipped amounts and traffic densities depend on the oil type. Thus the spill probability and effect of accidental releases will also depend on the oil type;
- It should incorporate the fate of the oil and hence include an oil (and chemical) processes module;
- The forcing of the modelling needs to consider all conditions when deriving risk, which means that hydrodynamics, wind and temperature will need to represent climatic, long term, conditions;
- The tool should be applicable to different areas and handle a variety of conditions (warm/temperate etc) and in areas that have significant periodical/seasonal climatic variations, this should also be accounted for;
- Since traffic routing and intensity changes continuously with time, the system will need to be updated from time to time (e.g. every 2-5 years);
- It is envisaged that many users will have access to the system, which means that databases, in which extensive datasets will be stored, will need to be standardised. The databases will contain a large variety of information needed to derive risk, such as a shipping database (including shipping routes and density of shipping), amount of transported substances, detailed characteristics of oils such as physical properties and chemical composition;
- It appears logical that exposure intensity (concentration) and exposure time are factors that affect the (environmental) damage. Hence, the results from the probabilistic modelling should also include a representation of these factors. The final risk map, where these results are combined with the vulnerability map should also account for the effect of exposure intensity and time;
- Results should be presented in an easily understandable format, in the form of maps or simple tables;
- The system should be embedded in a GIS environment and possibly web based to allow general access;
- The system may be interactive, giving the user the ability to test different GIS-layer combinations to derive a limited number of, for example, risk indicators.

2.3 General description of the risk tool

From the general requirements, outined in Section 2.2 for the design of a conceptual risk tool, a first outline is given in *Figure 1*.

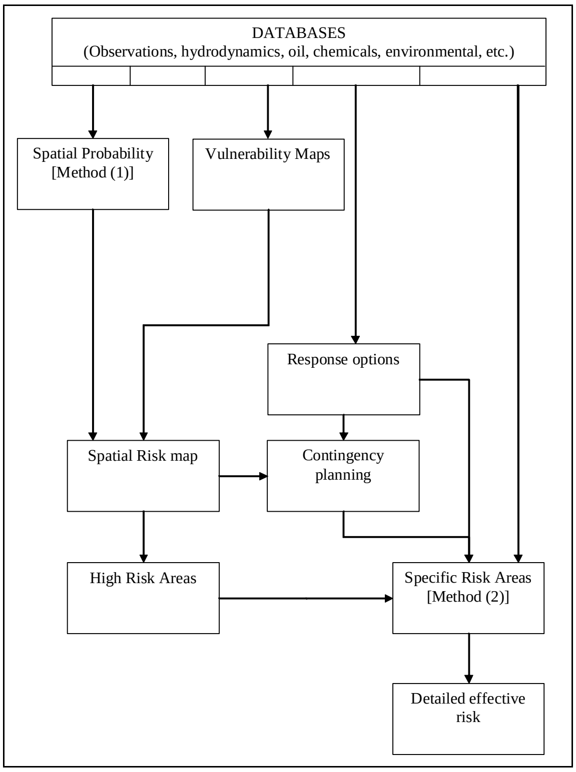


Figure 1 – Draft outline risk assessment tool

The main elements of the tool, which will be embedded within a GIS and/or Web based environment are:

- Extensive database, including shipping information, currents, water levels, salinity, ecological information historical data etc. The database should at least hold information that is required by the system, although it may contain additional useful information;
- General spatial probability module – this is a tool to calculate, using probabilities of spills from shipping accidents, the spatial distribution of the probability that pollution (e.g. oil) will be present. It therefore includes a hydrodynamic model and a pollution spreading model;
- Vulnerability mapping tool, using the extensive database to estimate the environmental vulnerability for a given type of pollution;
- Spatial risk map module in which the spatial presence probability and vulnerability are combined;
- High risk area definition module – the input to this module are the spatial risk maps, but also include criteria on which to base the selection of high risk area;
- Specific area probability distribution module, assessing in more detail the spatial pollution probabilities associated with specific locations. These locations may be chosen from the results of the general spatial probability distribution. This requires solving an inverse problem of identifying pollution sources that affect the chosen location;
- Contingency planning module – using the results of the general spatial probability module to optimise the locations of pollution combating equipment and derive procedures to optimise response to incidents;

- Response options module – from the extensive database and the type of pollutant, deriving the effects of different responses to incidents. This is focussed on specific areas and the optimal response results can be used in the development of contingency plans;
- Detailed effective risk module (method 2) evaluates the risk that remains after contingency planning has been put into operation. It takes account of oil processes, and focusses on specific locations and environmental conditions;

Expansion of this outline towards (near) real-time forecasting utlising remote sensing data appears a possibility, but is not yet included.

3 Demonstration of the methodology

3.1 Outline of the approach

In the present study, the demonstration of the overall methodology is based on the tools that are presently available. Some of the tools have been adapted to be applied here. The flow-diagram of Figure 2 is a more detailed diagram than figure 1 and it focuses on the combination of method (1) and the presently available V-maps of the Dutch Continental Shelf.

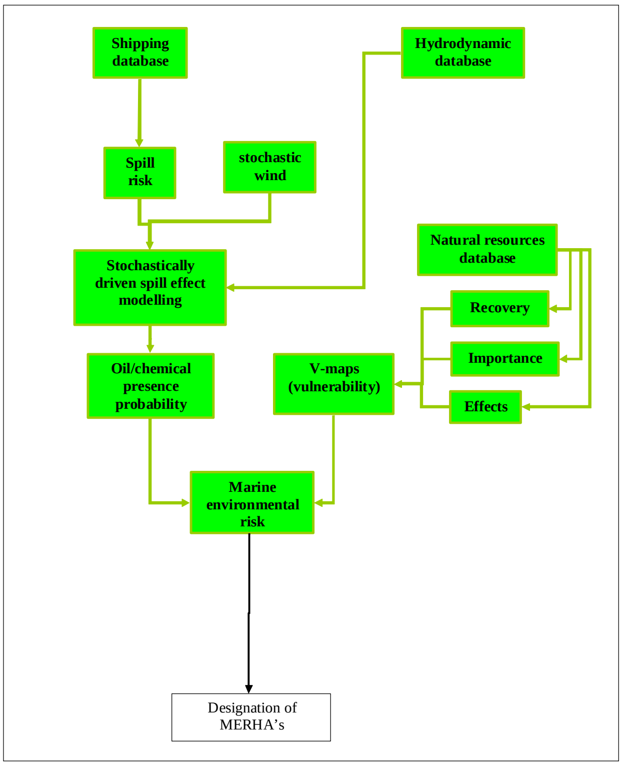


Figure 2 – Diagram of approach used in the demonstration

The boxes that are indicated by a green colour show the modules that are presently available and that have been applied in this study. The V-maps were developed and generated by Henk Offringa (Offringa and Lahr, 2006) and the spill risk calculations were carried out by MARIN using SAMSON (Safety Assessment Model for Shipping and Offshore on the North Sea, Koldenhof and van der Tak, 2003). This model calculates, based on traffic densities, the probability of collisions and the consequential oil spill sizes and frequencies. These spill risk distributions are used as input into the stochastic spill effect modelling.

In this demonstration exercise, the resulting risk maps have not been used to identify MEHRA's. The feasibility of deriving MEHRA's is addressed, but for an actual identification of MEHRA's additional development will be needed.

3.2 Stochastically driven spill effect modelling

3.2.1 *Definition of risk*

Risk (R) is defined as a combination of the probability of an event and the consequences of the event. The consequences are the result of exposure, E, and vulnerability, V. The vulnerability is expressed by Vulnerability Maps (V-Maps) as constructed by RIKZ and Alterra (details can be found in Offringa and Lahr, 2006). The exposure, E, can be described by numerous indicators, such as duration of the exposure, concentration, type of substance(s) etc. or by a combination of these factors.

The long term risk of accidental oil spills to the environment is expressed by the probability that oil is present in the marine environment (P_o) combined with exposure indicators (E) of the vulnerable area with a vulnerability index V, or:

$$R = (P_o * E) * V$$

The probability that oil is present in an area (P_o) depends on the probability that oil is released (spill probability - P_s) and how it is transported from the spill site to the vulnerable area. The link between the spill probabilities, P_s, and the oil presence probability, P_o, is made by a stochastic transport model, using climatic information. The risk maps that are generated, combine the spatial probability distribution of the oil presence (P_o), the exposure (E) and the vulnerability (V) of the affected area. The development of a detailed methodology to generate the spatial probability distribution of the presence of oil, P_o, is one of the essential elements of this study.

It is noted here that the presently available V-maps take account only of the presence and the type of oil and do not consider the duration of the exposure or the concentration. Because of this, the first step in the generation of the risk map is to estimate the spatial oil presence probability resulting from horizontal transport. Other processes that affect the fate of spilled oil are, at this stage, not considered. These spatial oil presence probability distributions (P-maps) are then linked with the V-maps tot generate spatial risk. At a later stage in the development of the methodology, these links can be refined to include more detailed information on exposure (different oil components) and vulnerability (down to e.g. species level).

3.2.2 *Generating spatial oil probability distributions*

Hydrodynamics

Transport of oil is driven by a combination of currents and wind. On short timescales, tidal currents dominate the transport, but on longer timescale average currents and wind stress drive the transport of floating oil. Tidal currents are well predictable and are simulated with an existing 2-dimensional model of the Southern North Sea using our Delft3D-FLOW model. For this demonstration of the methodology, average flow conditions over a spring-neap cycle are used, with average wind forcing to generate a general northerly residual current along the Dutch coast. It is noted that the direction and strength of the residual current varies and may affect the spatial distribution of spilled oil.

For the present demonstration, modelled tidal currents repesent average conditions and include an annual average residual current due to long-term average wind conditions in the southern North sea (7 m/s from the South-west).

Input of SAMSON spill probabilities

The oil spill probabilities provided by MARIN's SAMSON (Koldenhof and van der Tak, 2003) model serves as input to the oil model. The 8*8 km output grid cells of SAMSON, the so-called GENO grid, is used to define source locations of oil spills from shipping accidents in the oil transport model. Distributing source locations within the Dutch Continental Shelf with a spacing of 8km results in maximum number of potential source locations of approximately 900. The SAMSON results include spill frequency (i.e. return period) and the derived average spill size for each GENO gridcell.

Within the stochastic application of the oil model, the spatially distributed SAMSON discharge probabilities are assigned to each of the 900 sources. The resulting map combines all the modelled spatial oil distributions from all the individual sources into one probability map, indicating the probability of the presence of oil given the spatial probability distribution of the accidental oil releases throughout the Dutch Continental Shelf (thus representing a spatial distribution of P_o). In this setup spill sizes are not included and hence concentrations are not derived.

It should be noted here that spill probabilities outside the Dutch Continental Shelf are not available due to licensing agreements of the original shipping information for the Dutch Continental Shelf. Spill probabilities outside the Dutch Continental Shelf are not zero. Spills from outside the Dutch Continental Shelf will therefore affect the probability distribution inside the Dutch Continental Shelf. Furthermore, when oil is transported across the model boundary to outside the model, it cannot return to the model area. These boundary effects are noted here, but not considered in this demonstration.

The SAMSON model delivers per oil type discharge probabilities for 8 different spill size classes:

- Up to 20 m^3
- $20m^3$ and $150m^3$
- $150m^3$-$750m^3$
- $750m^3$-$3000m^3$
- $3000m^3$-$10000m^3$
- $10000m^3$-$30000m^3$
- $30000m^3$-$100000m^3$
- larger than $100,000m^3$.

The distribution of the total spill frequency (for all spill classes) for two oil types (Medium and Heavy crude) are shown in Figure 3. Heavy crude oil is one of the most common substances transported towards Rotterdam, whilst the medium crude is associated with the highest oil spill probabilities (Koldenhof and Bolt, 2007).

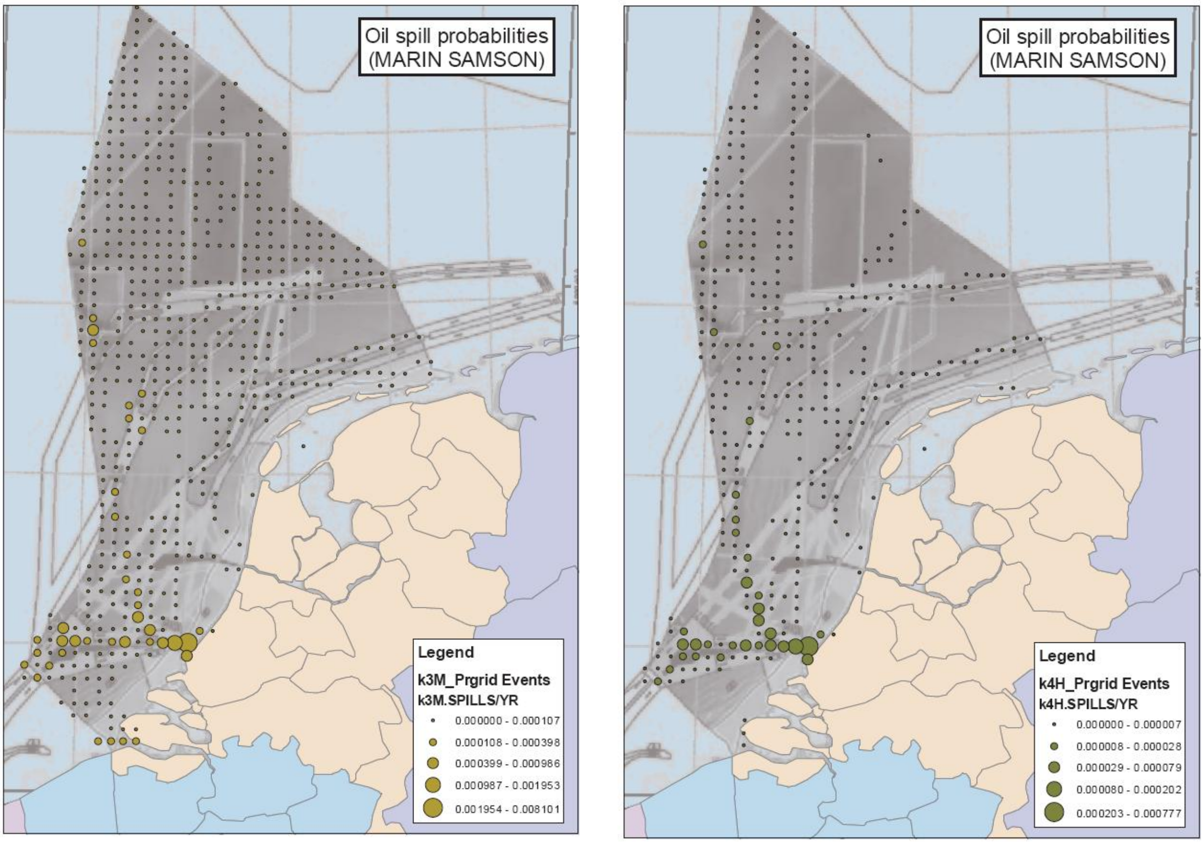


Figure 3 – Oil spill probabilities (number of spills per year) for all spill size classes and for Medium (class 3) and Heavy Crude oil (class 4)- demonstration only

For each of the 8 spill classes stochastic transport modelling is carried out, thus resulting in 8 oil presence probabilities for both oil types.

Wind forcing

Wind stress forces horizontal transport of floating oil. Wind statistics representing local (seasonal) conditions are required for the derivation of spatial probability maps.

The particle tracking model Delft3D-PART, used in this study, is driven by stochastic winds. The model uses long historical wind records from a wind database. From this database a large number of wind time series are taken with a starting time selected at random. The present oil model can handle up to 500 wind time series to represent long term wind statistics. The full set of wind information is then applied to the oil model in order to generate probability maps (spatial distribution of P_o) of the presence of oil given a spatial spill probability.

From the Royal Dutch Meteorological Institute (KNMI) long term wind data from IJmuiden was obtained, covering a 54-year period from 1952 to 2006. To drive the stochastic particle tracking model 500 wind timeseries were obtained with a length of 15 days by randomly sampling the observed houry wind series. The start of each wind series was randomly selected and the observed series for the following 15 days were taken and included in the stochastic wind dataset.

Stochastic modelling

The stochastic particle tracking model is run for each spill class and for each oil type, i.e. 16 runs in total. The simulation period of 10 days after oil release was selected for demonstration purposes. This simulation period is based on the premise that 10 days would be sufficient to respond to an oil spill and that boundary effects (that increase with time) would still be limited. The chosen simulation time is, however, a relative arbitrary one. The effect of the length of the simulation period on the results was not investigated in this study. The number of particles used in the model is calculated from 1 particle for each wind series (500) and for each spill location (up to 900).

Within the present stochastic model setup, oil processes (including spreading, evaporation, emulsification etc.) are not included, except for beaching. When an oil particle beaches, then it is immobilised for the remainder of the model simulation. It is recognised, however, that oil processes are important when assessing the environmental risk. However, the introduction of oil processes in a stochastic setting will require careful consideration because they cannot be included without the use of a number of indicators to represent the effect of time on the processes. These indicators will need to be developed and integrated into the system at a later date.

At this stage of the development of the methodology an instantaneous oil release is assumed. An instantaneous spill is a special case of a timed-release (continuous) spill and to extent the method to timed-release spills will require additional development. A variation of the timing of the release in relation to the tide is also not considered. An introduction of timed-release spills and timing of release adds two degrees of freedom in the stochastic modelling approach and requires careful consideration. The effects of these release variations on the Risk maps will need to be addressed at a later stage.

Model output is mapped on an output grid with a 5*5km resolution (the same as the resolution of the V-map).

Deriving oil presence probability

To derive the spatial oil presence probabilities using a large number of windseries that represent climatic conditions, it is assumed that there is no prediction uncertainty due to model inaccuracies. This implies that if the model would be applied in a deterministic mode, the model prediction will be 100% accurate. This is obviously not the case, but it is required to derive the stochastic methodology. The effect of model uncertainty (leading to prediction errors) will need to be investigated at a later stage.

When the model is applied for N_w number of different wind series, and it is assumed that each wind series has the same probability of occurrence, then for every timestep each simulated oil patch that is associated with one wind series represents a probability of $1/N_w$. If in one area, presence of oil at time t is simulated by n patches (associated with n wind series), then the overall probability of the presence of oil for that area will then be n/N_w. Thus a probability is derived for every timestep.

This instantaneous probability is generated for each receptor grid cell (*ng*) thus creating a spatial map representing the overall instantaneous probability distribution of the presence of oil after time t following an instantaneous oil spill.

The instantaneous probability distributions as a function of time are then integrated over time for the duration of the simulation (t_{end}). In this procedure, the duration of the presence of a particle in a receptor grid cell is monitored by the model and this residence time is used when deriving the probability of oil being present. This principle of deriving the presence probability at one receptor cel *ng* orginated from one source location *nl*, is summarised as:

$$p_{nl,ng} = \int_{t=0}^{t_{end}} \frac{n_{nl}(t,ng)}{N_w t_{end}} dt$$

If more than one source is used then the probability map can be produced for each discharge location (*nl*). These probability maps can then be combined to an overall probability map showing the risk of each grid cell being polluted. Since the assumption is that the releases are independent events, then the overall oil presence probability for a receptor location *ng* is defined by:

$$P_{ng} = 1 - \prod_{nl=1}^{NL} \left(1 - p_{nl,ng}\right)$$

where *NL* is the total number of discharge locations (source areas) used in the simulation.

Up to now it has been assumed that all the sources have the same probability (of 1), but the input to the model is based on the actual spatial spill probabilities from shipping, that are generated by SAMSON. By associating the spill probabilities to the particles that are released from the source locations, the resulting spatial probability map reflects the effect of the spatially distributed spill probabilities.

3.2.3 *Combining oil presence probabilities with V-maps*

The oil presence probabilities as indicated above need to be combined with the vulnerability (V-maps) to generate an spatial representation of risk. There are many ways by which this can be done, but a few principles should form the basis for the link.

- The higher the oil presence probability with a constant vulnerability, the larger the environmental risk;
- The more vulnerable the area with the same oil presence probability, the larger the risk;
- The larger the spill volume, the larger the environmental damage, because a larger spill will cover a larger area and will have a greater impact.

These three basic assumptions have been applied in this study to generate the Risk maps.

When, at a later stage, processes and actual spill sizes are included, then the effects of concentrations and amounts on the environmental damage can be specified in more detail.

3.3 Description of modelling software

3.3.1 *Introduction*

For a reliable risk assessment methodology it is necessary to be able to predict the transport and fate of the spilled substances. This is best achieved when using a calibrated and validated hydrodynamic model. There are many hydrodynamic models available, but for this project use is made of Delft3D-FLOW, because an operational model of the southern North Sea was readily available.

In addition to the hydrodynamics, a pollution tracking model is needed. The model will need to be able to operate stochastically, which limits the type of model to so-called particle tracking models. For this type of model, a large number of “particles” are released, representing the spilled substance, and the coordinates of each particle is tracked during the simulation. The transport of the particles are driven by the hydrodynamics and wind stress. In this study the Delft3D-PART was applied because it can make direct use of the output from the Delft3D-FLOW hydrodynamic model. The model was also adapted to enable the input of stochastic wind information providing the means to develop the risk maps. To include the processes that affect the fate of spilled oil in the risk assessment, an oil module will be required. This may be included in the particle tracking model, such as the Delft3D-PART model or SINTEF’s oil weathering model (OWM).

3.3.2 *Delft3D-FLOW*

For the simulation of the water levels and currents, the 3-dimensional hydrodynamic module Delft3D-FLOW is applied.

Delft3D-FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a curvilinear, boundary fitted grid. In 3D simulations, the vertical grid is defined following the sigma coordinate approach.

The standard features of Delft3D-FLOW are:

- Tidal forcing.
- The effect of the Earth’s rotation (Coriolis force).
- Density driven flows (pressure gradients terms in the momentum equations).
- Advection-diffusion solver included to compute density gradients with an optional facility to treat very sharp gradients in the vertical.
- Space and time varying wind and atmospheric pressure.
- Advanced turbulence models to account for the vertical turbulent viscosity and diffusivity based on the eddy viscosity concept. Four options are provided: k-ε, k-L, algebraic and constant model.
- Time varying sources and sinks (e.g. river discharges).
- Simulation of the thermal discharge, effluent discharge and the intake of cooling water at any location and any depth.
- Drogue tracks
- Robust simulation of drying and flooding of inter-tidal flats.

3.3.3 *Delft3D-PART*

The PART module of Delft3D simulates transport and simple water quality processes by means of a particle tracking method using the (2 or 3-dimensional) flow data from the FLOW module. The tracks are followed in three dimensions over time, whereby a dynamic concentration distribution is obtained by calculating the mass of particles in the model grid cells.

Delft3D-PART is a random walk particle tracking model, which is based on the principle that the movement of dissolved (or particulate) substances in water can be described by a limited (large) number of discrete particles that are subject to advection due to the currents and by horizontal and vertical dispersion. The movement of the particles consists therefore of two elements. For each time-step, the first step is the advection step due to the shear stresses from currents (bottom) and wind (surface). The second step is the random walk step in which the size and direction of the movement is a random process but is related to the horizontal and vertical dispersion.

Particle tracking allows water quality processes to be described in a detailed spatial pattern, resolving sub-grid concentration distributions.

In Delft3D-PART, two modules are available:

- Tracer module: simulation of conservative or first order decaying substances
- Oil spill module: simulation of oil spills with floating and dispersed oil fractions.

The Delft3D-PART Oil Spill model calculates the transport and fate of an oil patch in the marine (aquatic) environment. The processes that are included in the module are:

- The advection of surface floating oil due to currents and wind drag;
- Evaporation of floating oil (first order process) of the volatile fraction of the oil;
- Dispersion of floating oil, or entrainment of oil in water, a process that is driven by wave action and depending on oil characteristics (viscosity);
- Emulsification of oil, leading to water-in-oil (w/o) emulsions that form a viscous cream, or floating, coherent semi-solid lumps, often called *chocolate mousse*. The process depends on oil composition.
- Sticking of oil to the coast or seabed;
- Settling of dispersed oil (entrained in water) due to adsorption of oil droplets to suspended solids;
- Weathering of oil due to, for example, oxidation, and bacteriological decay can in PART be simulated by means of a first order decay, for which a decay parameter can be specified.

Over the last couple of years, WL | Delft Hydraulics has carried out research to apply the Delft3D-PART (Oil) model in a fully stochastic mode thus using statistical wind information to efficiently derive oil distribution probability maps (e.g. Kleissen, 2004).

3.4 Probabilistic modelling using Delft3D-PART

3.4.1 *Specific demonstration implementation*

For the demonstration of the methodology, use is made of available V-maps and SAMSON results. From all the results selections were made for the demonstration.

Digital V-maps (as ARCMAP shapefiles) were available for ecological vulnerability to REBCO oil, which is a Russian Heavy Crude oil. The results are generated for 6 2-month periods. For this demonstration, period 1 (August-September) and period 5 (April-May) were selected.

Results from SAMSON were available for 7 oil types, varying from light crude to heavy crudes. Heavy fuel oil was also included in the SAMSON results. Of the available oil types in SAMSON, two different oil types were considered in this demonstration. The oil types used in the demonstration are:

- Class 3 – Medium Crude oil
- Class 4 – Heavy Crude oil

The Heavy Crude was chosen because it is one of the most common substances transported towards Rotterdam, and is closest related to the REBCO oil for which the V-maps were available. Class 3 oil was indicated by the results from MARIN to be associated with the highest spill frequencies.

3.4.2 *Stochastic modelling results*

For each oil type and each spill size class the model was run over a period of 10 days. Model output was generated every hour. At the end of each run the output is combined into a oil presence probability map during the run. All these results are shown in Appendix A.

For each oil class an overall probability that oil will be presence in a 5*5km gridcell is derived from the individual spill size classes, assuming that the spill classes are independent. The derived probability maps are in Figure 4.

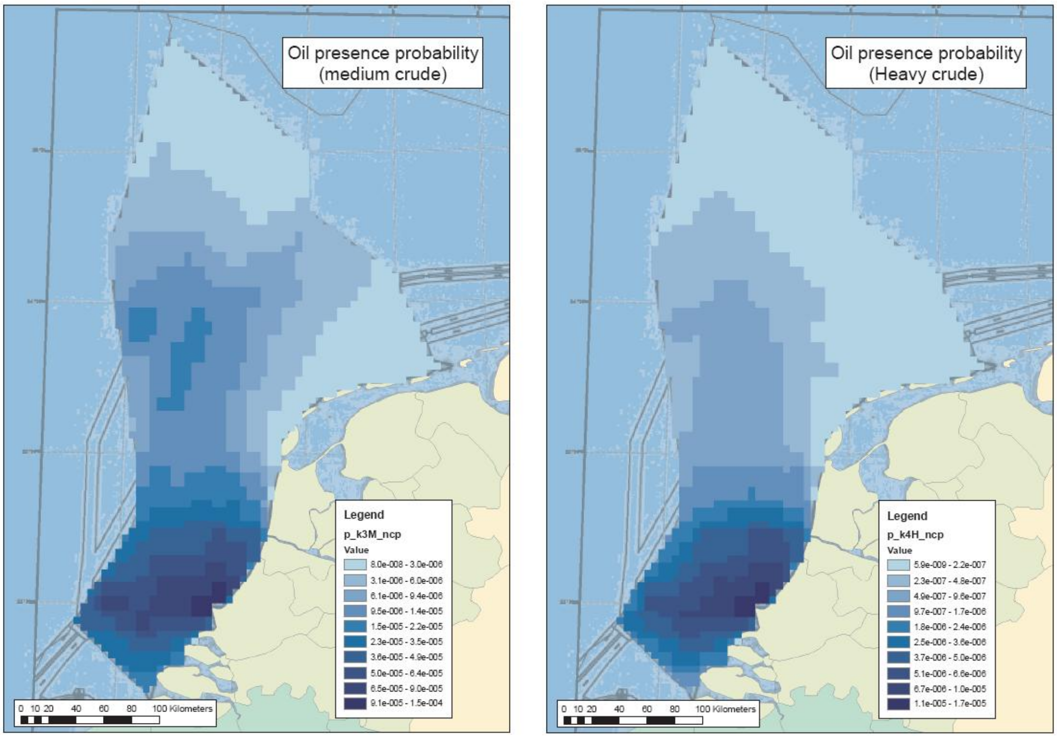


Figure 4 – Oil presence probability of heavy crude (left) and medium crude (right) – demonstration only

It is seen that the highest probabilities for both oil types are centred around the entrance to Rotterdam Harbour. In general the probabilities of medium crude are about a factor of 10 higher than for heavy crude, reflecting the higher incident (spill) probability (per year and within a 10 day period after a spill).

The boundary effect, mentioned earlier, can be noted near the southern model boundary. Assuming that the residual current is about 5 cm/s, then in 10 days time (simulation duration) the travelled distance is approximately 40 km. This is the zone around the boundary that is potentially affected by the fact that no shipping information is available outside the Dutch Continental Shelf.

3.5 Deriving Risk maps within a GIS environment

All results from the stochastic modelling, the source of the pollution (spill probability distribution from shipping accidents) and V-maps have been setup in a GIS environment (ArcMap 9.0).

This provides the means to examine the link between the oil presence probabilities and the V-maps.

To establish the link between the oil presence probabilities and the V-maps, two periods were selected, period 1 (August-September) and period 5 (April-May) because they indicate significant different vulnerabilities with a relatively large spatial variation (Figure 5).

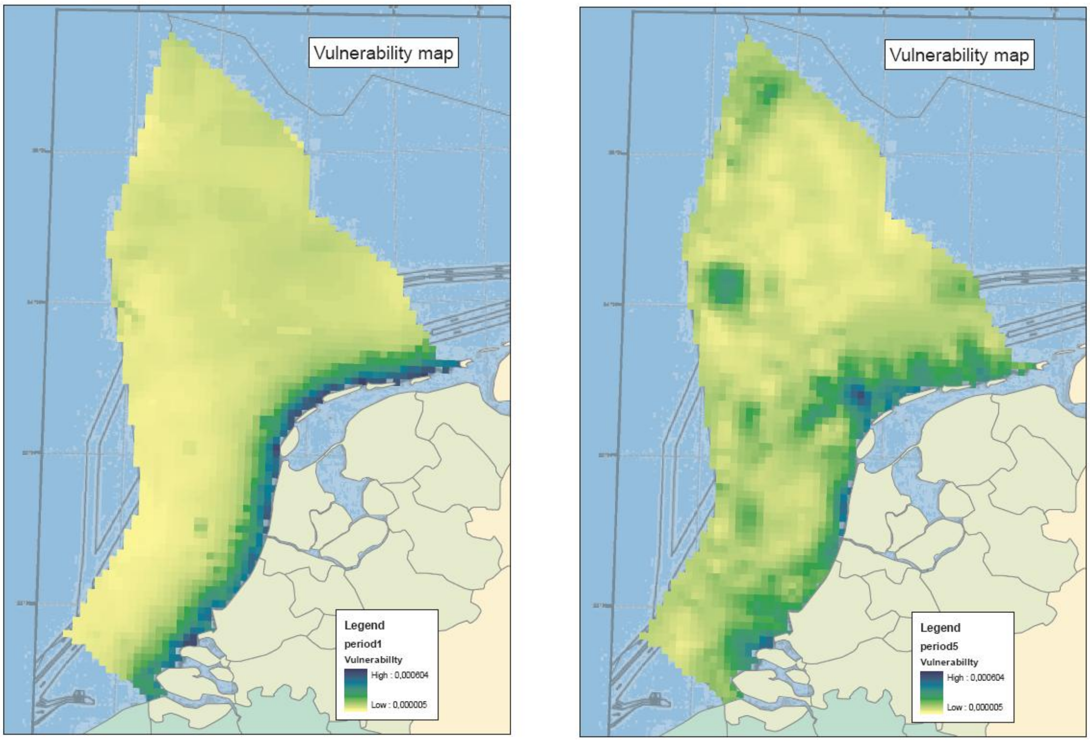


Figure 5 – V-maps (REBCO oil) for period 1 (left) and period 5 (right)

The stochastic application has not accounted for possible different wind characteristics for the two periods, although for a future system this would need to be included.

When generating the risk maps, the size of the spill should be accounted for. Even though small spills have, in general, a higher frequency of occurrence, a large spill will inflict significantly more damage when it happens. Thus the individual oil presence probabilities are weighted with the average spill volume as generated by MARIN. There are many ways in which this can be done, but several experiments have shown that the manner of weighting is of limited significance when deriving the total risk. For a first application a simplified assumption has been adopted in which average spill size is introduced as the indicator of Exposure. Thus, for each oil type (*o*) and spill size (*s*) the risk map is derived from:

$$R_{os}=P_{os}\cdot E_{os}\cdot V$$

Since it is assumed that the Risk is an indicator for long term damage, we have opted to obtain the total risk of an oil type by adding the probability contributions of the 8 individual spill size classes (P_{os}), weighed with the average spill size (E_{os}), and then to combine the result with the V-map:

$$R_o=\left(\sum_{s=1}^{8} P_{os}\bullet E_{os}\right)\bullet V$$

The resulting maps, for the medium and heavy crude for periods 1 and 5, are presented in Figure 6 and Figure 7.

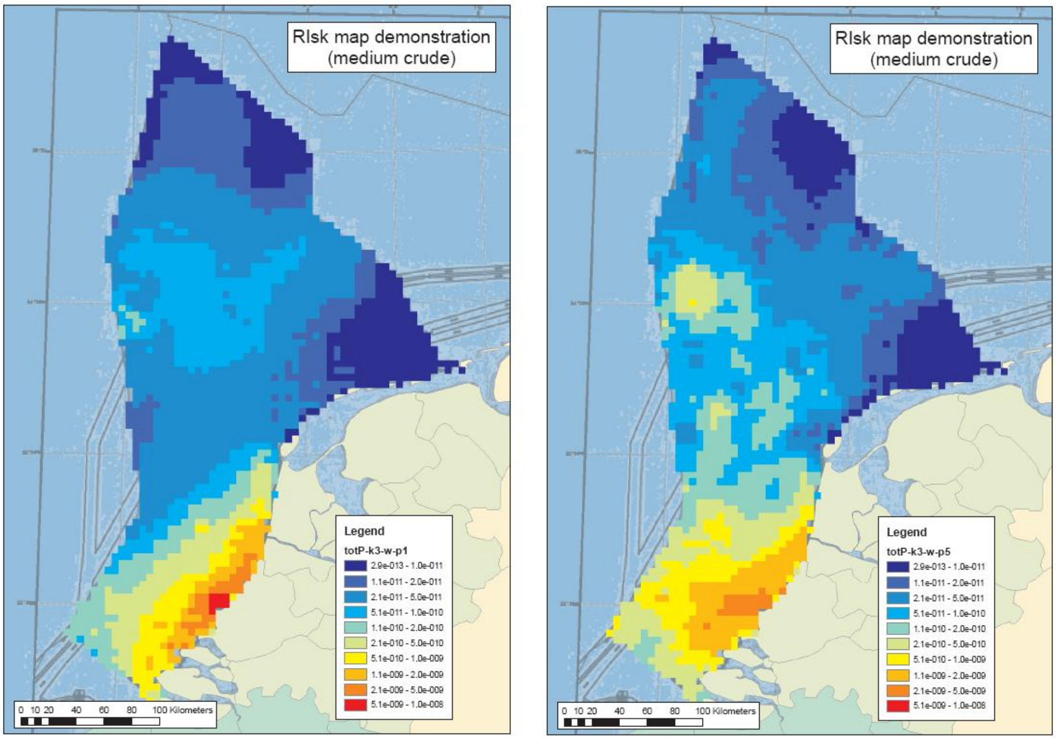


Figure 6 – Risk map for medium crude for period 1 (left) and 5 (right) – demonstration only

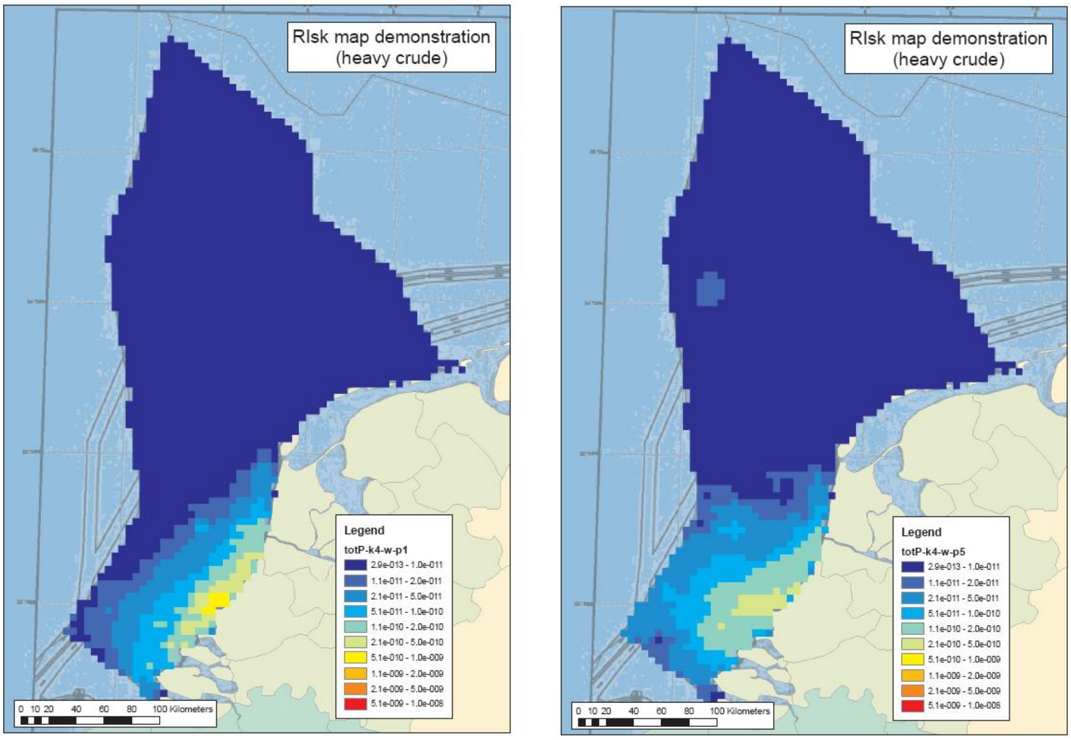


Figure 7 – Risk map for heavy crude for period 1 (left) and 5 (right) – demonstration only

The maps show that the areas of high vulnerability result in higher risk values. For period 1, the higher risks are located near the Dutch coast, whilst for period 5 there are also off-shore areas that have a higher risk value. The risk as a result from the heavy crude is significantly smaller than for the medium crude, although it should be realised that the V-map used in this demonstration is derived for REBCO oil, which is a heavy crude oil. A V-map for a medium crude may differ from the map used here and may therefore affect the Risk map.

The actual risk values as presented here (Figure 6 and Figure 7) are difficult to interpret. The figures represent one manner in which to present the results. However, risk can be presented quantitatively (absolute or relative values) or qualitatively (in terms of “high”, “medium”, “low” etc.). Criteria on the significance of these values will be needed. If, for example, the values would be used to estimate the number of animals affected per year, then this may provide the means to assess whether a risk value is significant or not. The advantage of using numerical risk values is that values from difference areas may be compared, as long as the used assumptions and methods are the same. If no consensus is possible on these criteria then a relative risk assessment can be carried out showing, for example, 10% of the modelled area most at risk. However, if the risk is insignificant then even the high risk areas could represent no significant risk. Hence, how the results will be used in the selection of MEHRA’s and how the results are presented will need to be considered carefully.

Seasonally derived risk maps

Vulnerability maps were available for six 2-monthly periods of which 2 periods were investigate in more detail. To show that seasonality of climatic conditions can be a factor in generating a risk map, winds were also randomly selected from the long term record for the two periods: Period 1 (August/September) and period 5 (April/May). For the Heavy Crude (analogue to the REBCO oil) seasonal spatial oil presence probability maps (P-maps) were generated and combined with the appropriate V-maps, using the same weighting of the average spill sizes as used earlier. The results are shown in Figure 8.

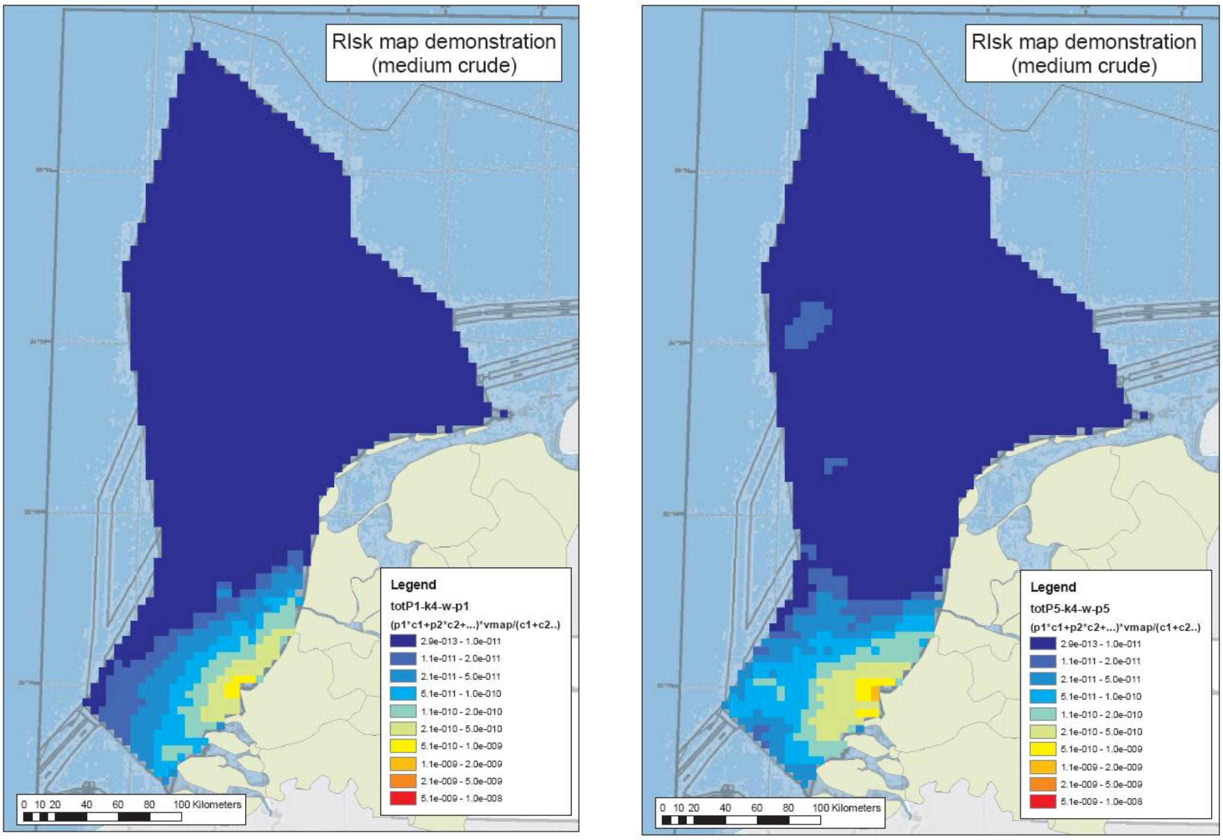


Figure 8 – Demonstration of seasonal effects on risk map for period 1 (left), period 5 (right)

The difference between the two maps of Figure 8 is due to the difference wind conditions and vulnerability. It is noted here that the hydrodynamics was driven by annual average winds and not seasonal average wind. This may effect residual flows and therefore the oil presence probability. When only examining the effect of the wind, then a comparison can be made between Figure 7 and Figure 8, showing the extent of seasonal wind effects.

3.6 Deriving MEHRA’s

The risk maps of Figure 8 show the contours of the different risk levels. The methodology that was adopted by Safetec, on behalf of the UK Government (DEFRA), in the UK in 1999 (MacDonald et al, 1999) focussed on the 10% of the area judged as being most at risk. It is noted here that the UK MEHRA’s only cover the UK coastline and include other factors such as economic issues and are therefore not comparable with the MEHRA’s discussed here. Based on this, the risk maps of Figure 8, were simplified to show the 10% of the NCP area with the highest risk values, the 40% area with a relative medium risk and the remainder of the area (50% of the total NCP area) that has lower risk values. The resulting figures show the seasonal effect which may affect the identification of MEHRA’s.

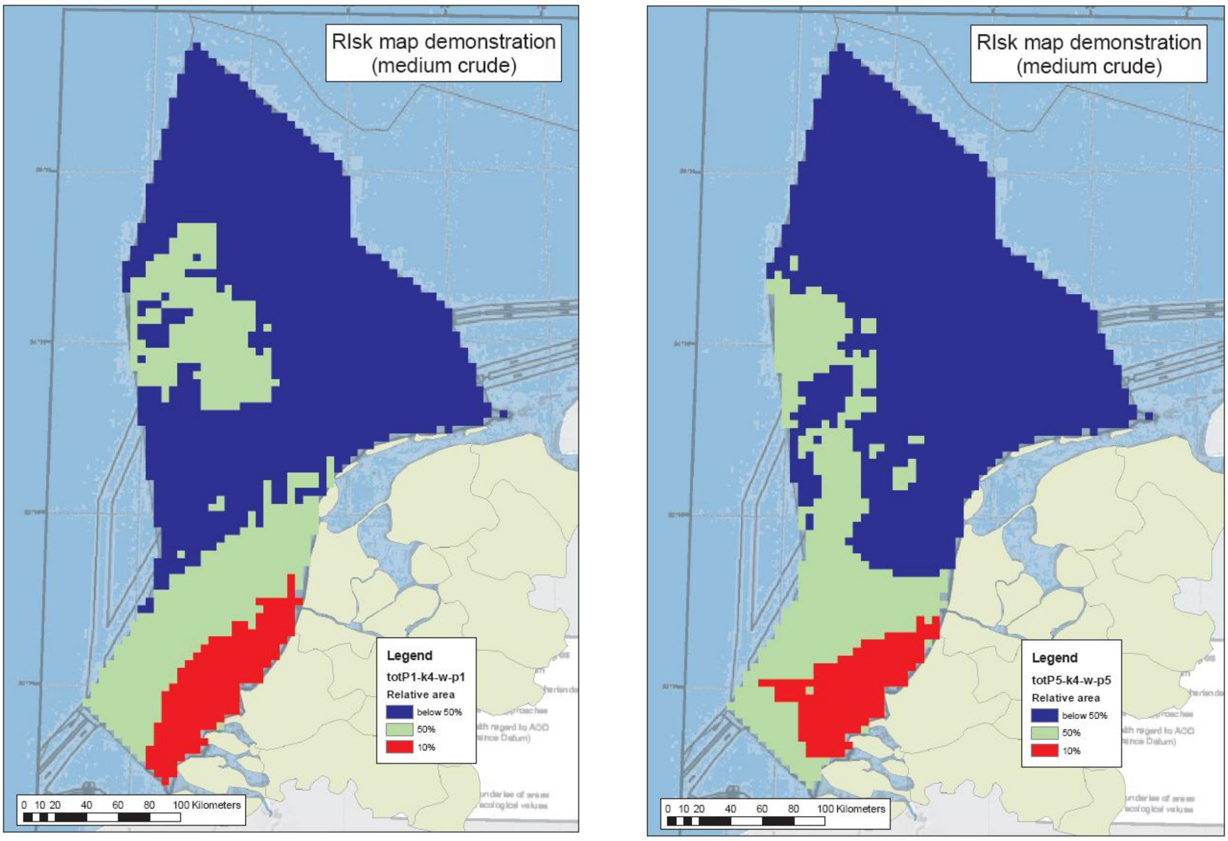


Figure 9 – Relative risk distribution for period 1 (left) and period 5 (right) – Demonstration only

The results that are shown here should at this stage not be used to designate High Risk Areas, because the methodology that is used here requires further development with refining the manner in which the risks area derived (for some considerations see Appendix B). This demonstration has shown, however, that the approach is promising and that results can be presented into an easily understandable format.

4 Conclusion and Recommendations

4.1 Conclusion

The development of risk maps for the Dutch Continental Shelf has utilised new methodologies to generate a spatial distribution of Risk to the environment from oil spills. This approach has linked spatial distribution of spill probabilities (derived by MARIN using SAMSON), hydrodynamic and climatic (stochastic) wind forcing of the transport of oil and Vulnerability maps to derive an overview of long term risk to the environment from accidental oil spills.

The demonstration presented in this report has shown that with available tools and techniques, generation of general risk maps provides valuable insight in areas that have a relative high risk of environmental damage due to accidental oil spills.

4.2 Recommendations

Even thought the main tools are available and the approach followed here is very promising, the vision of a European harmonised approach to risk mapping (see for an outline ***Figure 1***) requires a significant amount of further work. It is envisaged that such a system would consist of the generation of general risk maps, such as shown here, after which selected areas are investigated with a more site specific approach.

The approach used in this study can also be developed further and the main items that have not yet been included are:

- We have used average hydrodynamics, but it is not known in detail how the variability of (residual currents) affect the general risk map;
- Wind is assumed to be uniform across the model area, which means that the area that is investigated will be limited. The use of spatially varying wind conditions within the present stochastic setting will require additional development;
- Implementation of oil processes, such as evaporation, entrainment, emulsification etc. The manner in which oil is present in the environment will be an important factor in determining damage. In the spatial stochastic setting the implementation of this requires further development, because the time evolution of the processes within the stochastic setting needs appropriate indicators that have not yet been developed;
- When oil processes are included, then the vulnerability to the individual oil fractions (evaporated/dispersed/adsorption to sediment/dissolution etc) will be needed to assess risk. This means that the generation of V-maps would need to be able to account for the presence of these oil fractions.
- The manner in which the results (Risk maps) will be used in the selection of MEHRA's and how they are presented and communicated to others will need to be considered carefully.

5 References

Bolt E. (2006) Crude Oil and Residual Fuel Oil Transport on the North Sea. Safety at Sea Demonstration Project A Report No A01-2.

Kleissen F.M. (2004) Risk assessment of calamitous spills in the spatial domain – Implementation and application of stochastic winds and exposure maps, WL | Delft Hydraulics R&D report Z3505, December 2004

Koldenhof Y. and van der Tak C. (2003) Vervoer (milieu)gevaarlijke stoffen over zee in 2000. MARIN Report 18807.620/2 (in Dutch).

MacDonald A., McGeechan C., Cain M., Beattie J., Holt H., Zhou R, and Farquhar D. (1999) Identification of Marine Environmental High Risk Areas (MEHRA's) in the UK, Safetec Report No: ST-87639-MI–1-Rev 01, on behalf of Department of the Environment, Transport and the Regions in the UK.

Koldenhof and Bolt (2007) Safety at Sea, Demo A: Inventory, classification and risk assessment of oil transport in the North Sea – Risk Study on the Outflow of Oil on the Dutch Part of the North Sea, Report No A06

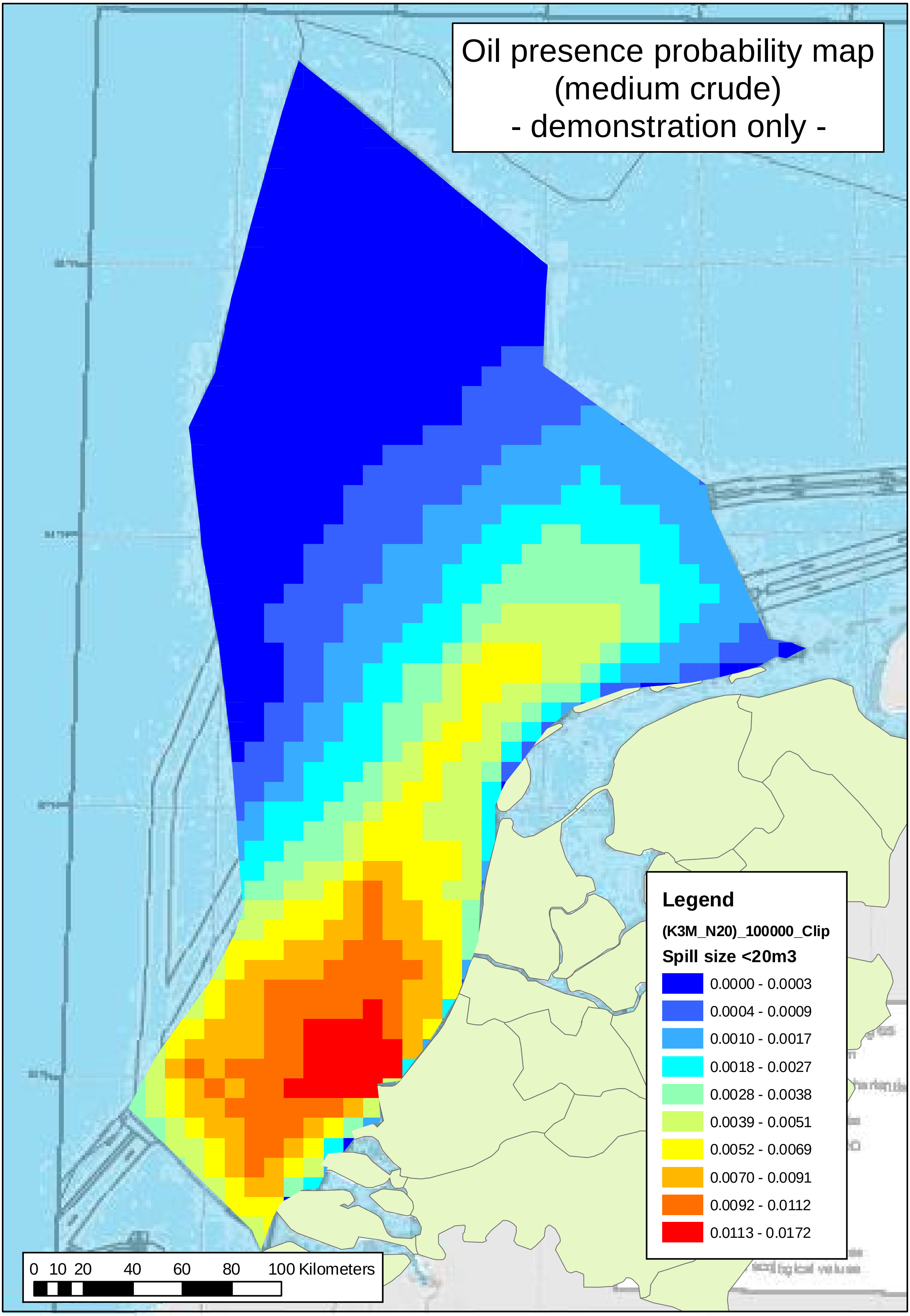
Offringa, H.R. & Lahr, J. (2006) An integrated approach to map ecologically vulnerable areas in marine waters in the Netherlands (V-maps). RIKZ working document RIKZ 2006-xxx. Ministry of Transport, Public Works and Water Management, Rijkswaterstaat, National Institute for Marine and Coastal Management, the Hague.

Skognes, K. and Johansen, Ø. (2004) Statmap – a 3-dimensional model for oil spill risk assessment, Environmental Modelling and Software, Vol. 19, pp:727-737

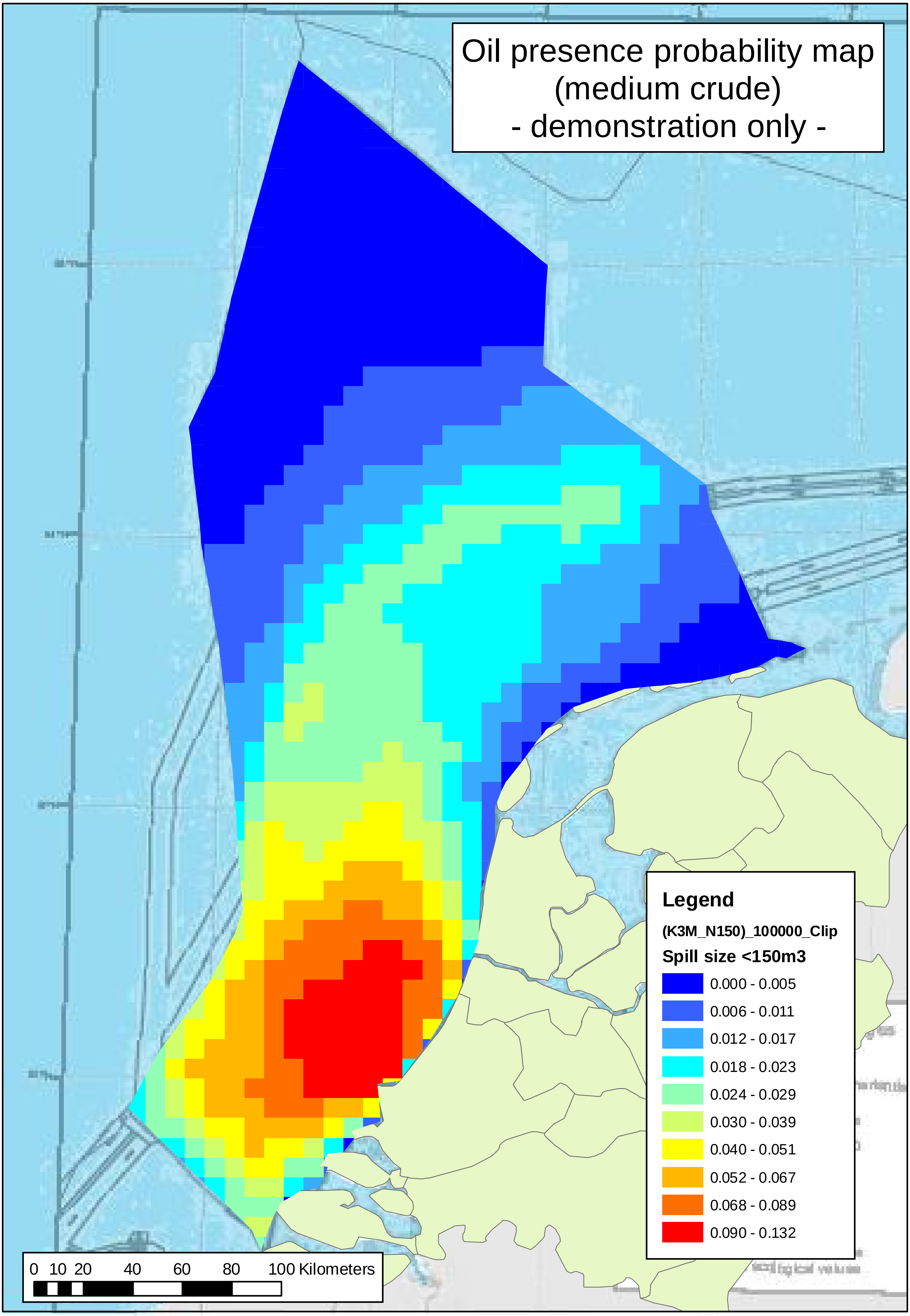
Appendix A

Spatial Oil presence probability maps

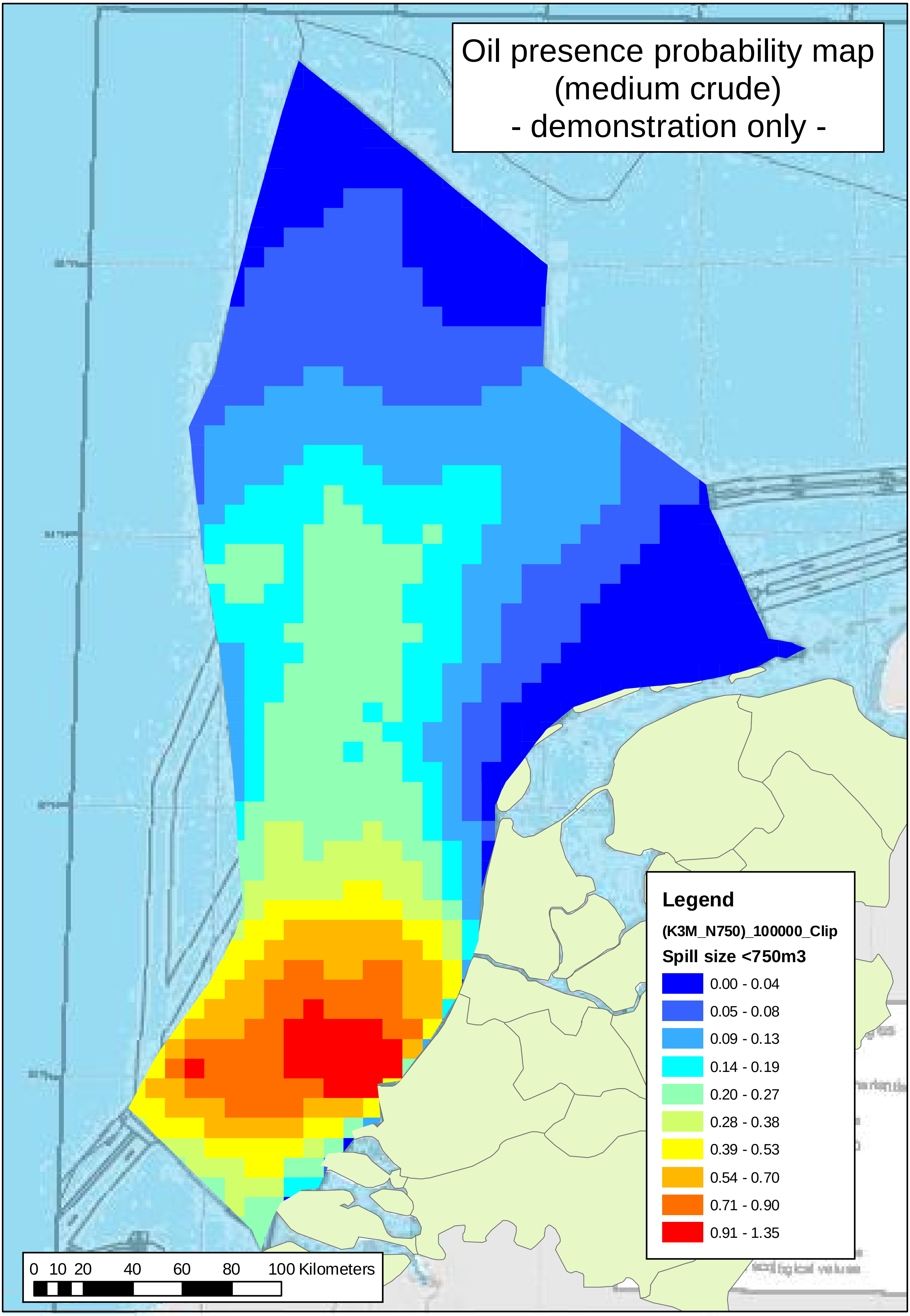
(note: probability values in the figures are scaled up by 10^5)



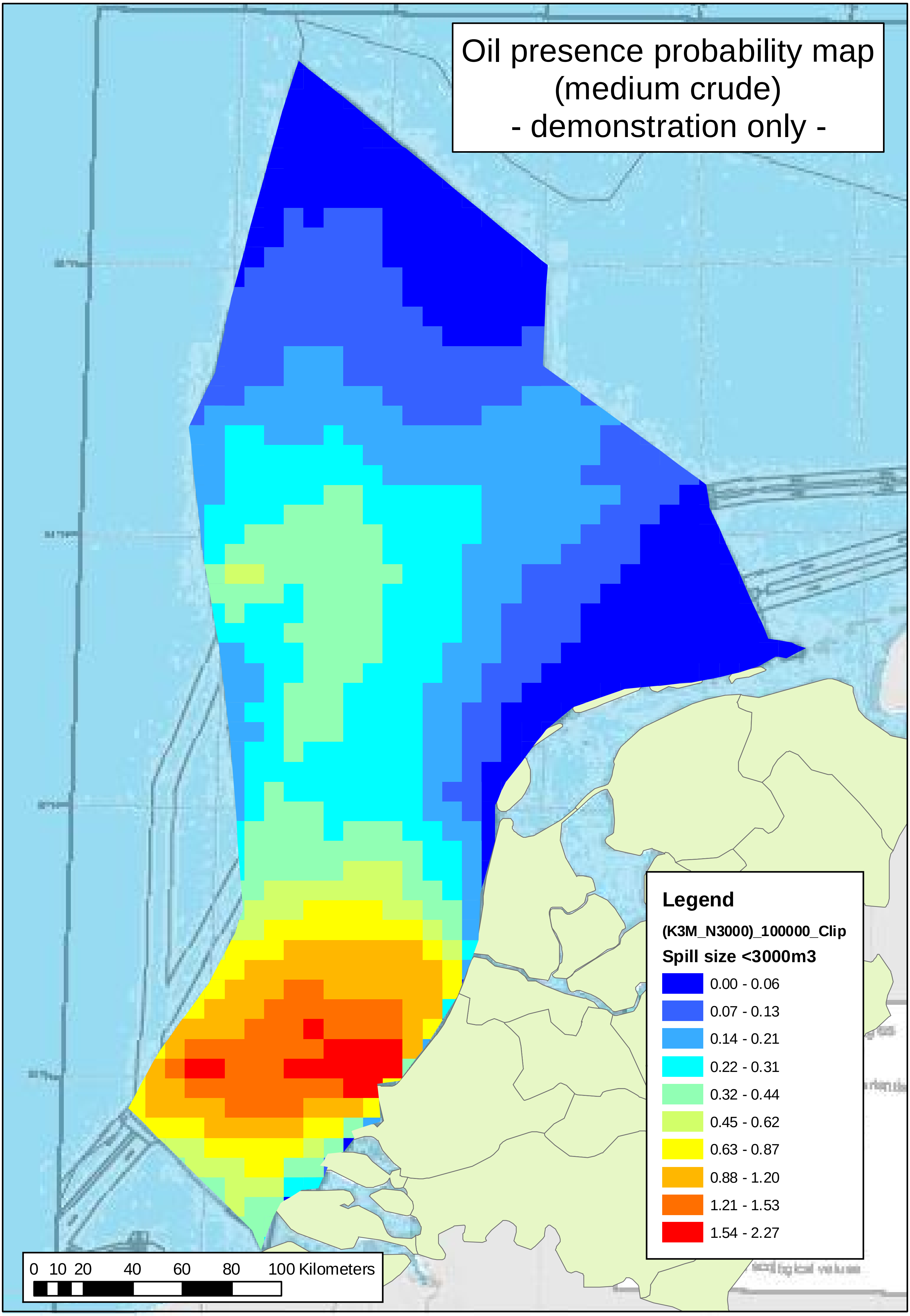
Oil presence probability map
(medium crude)
- demonstration only -

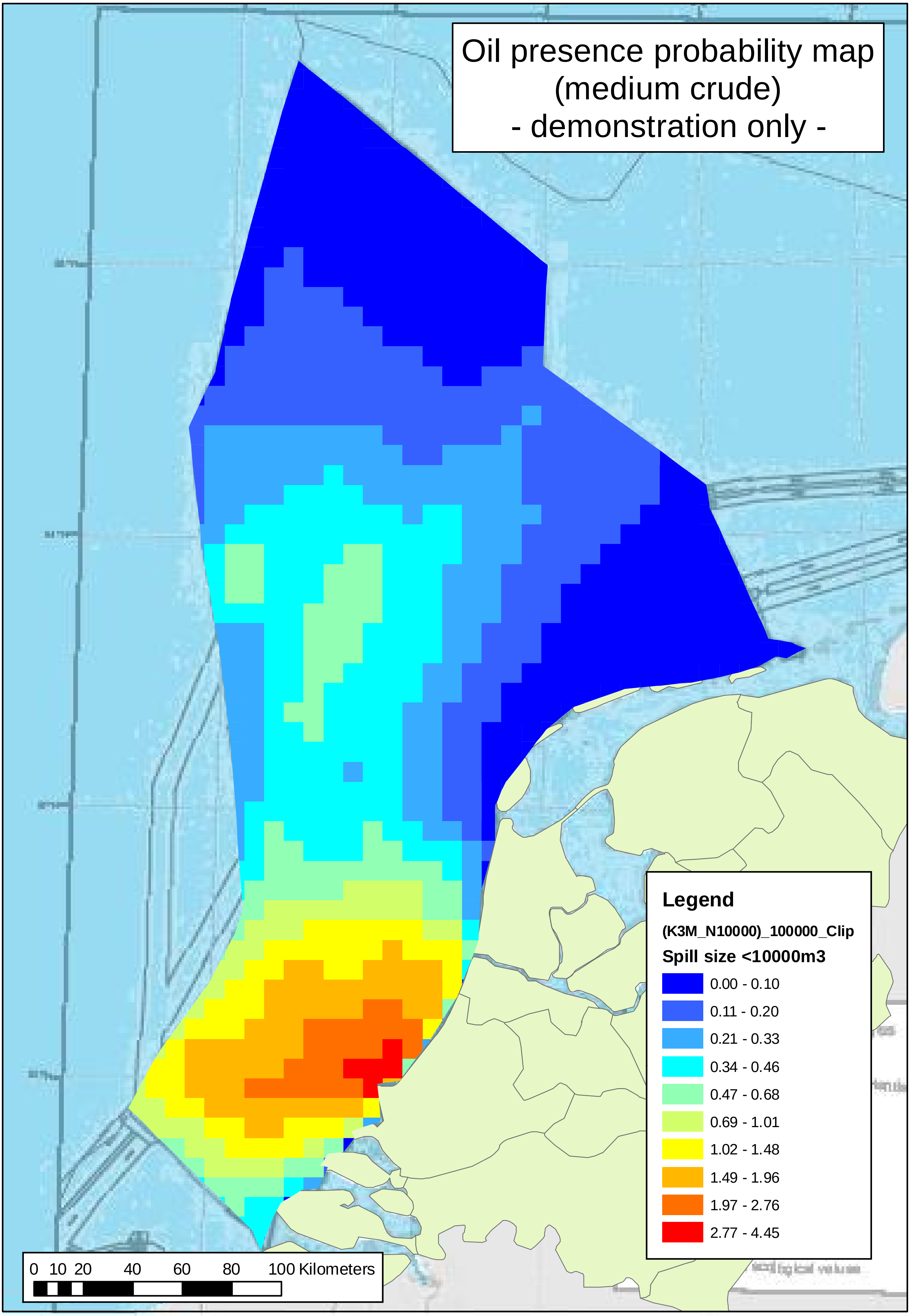


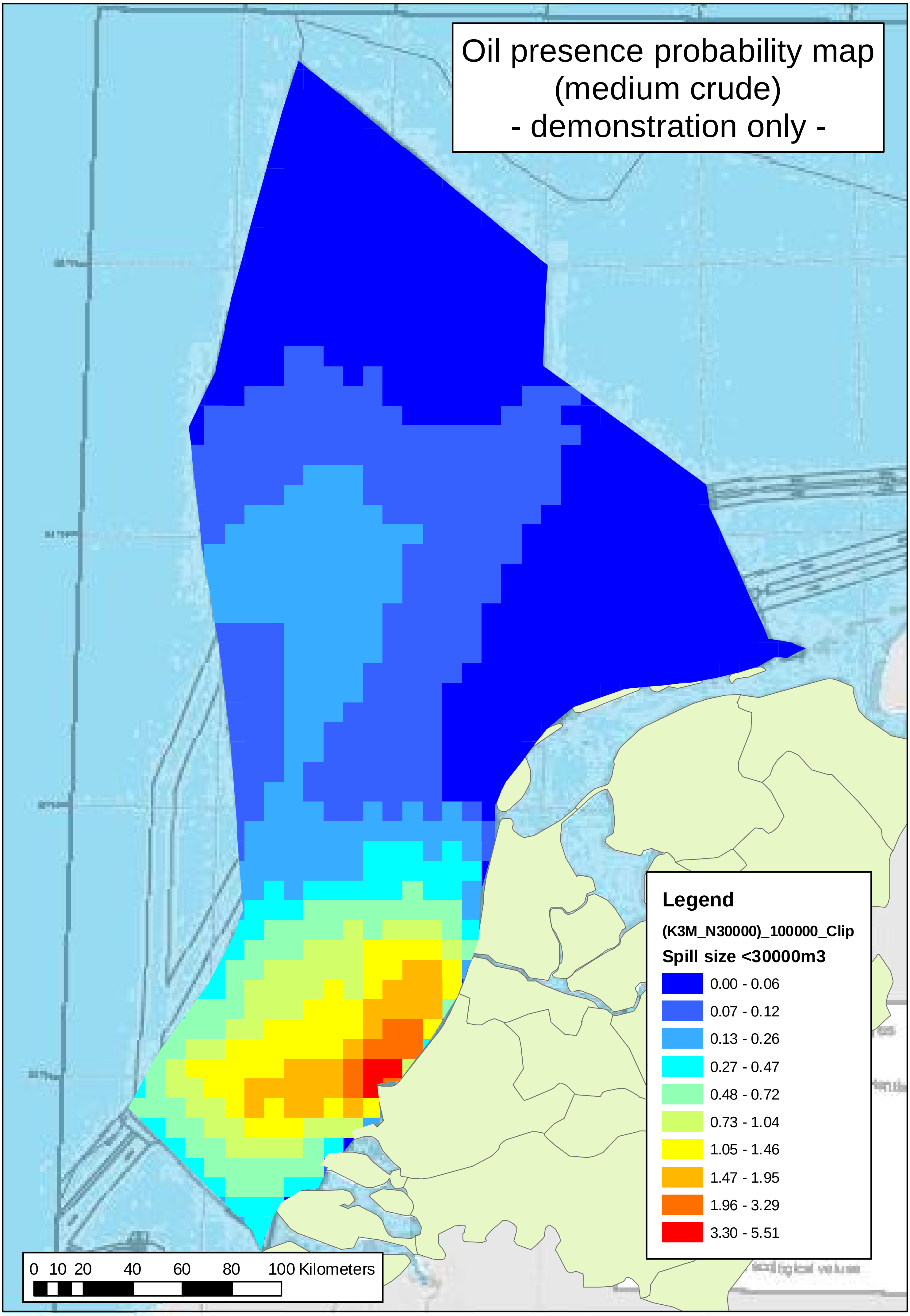
Oil presence probability map
(medium crude)
- demonstration only -



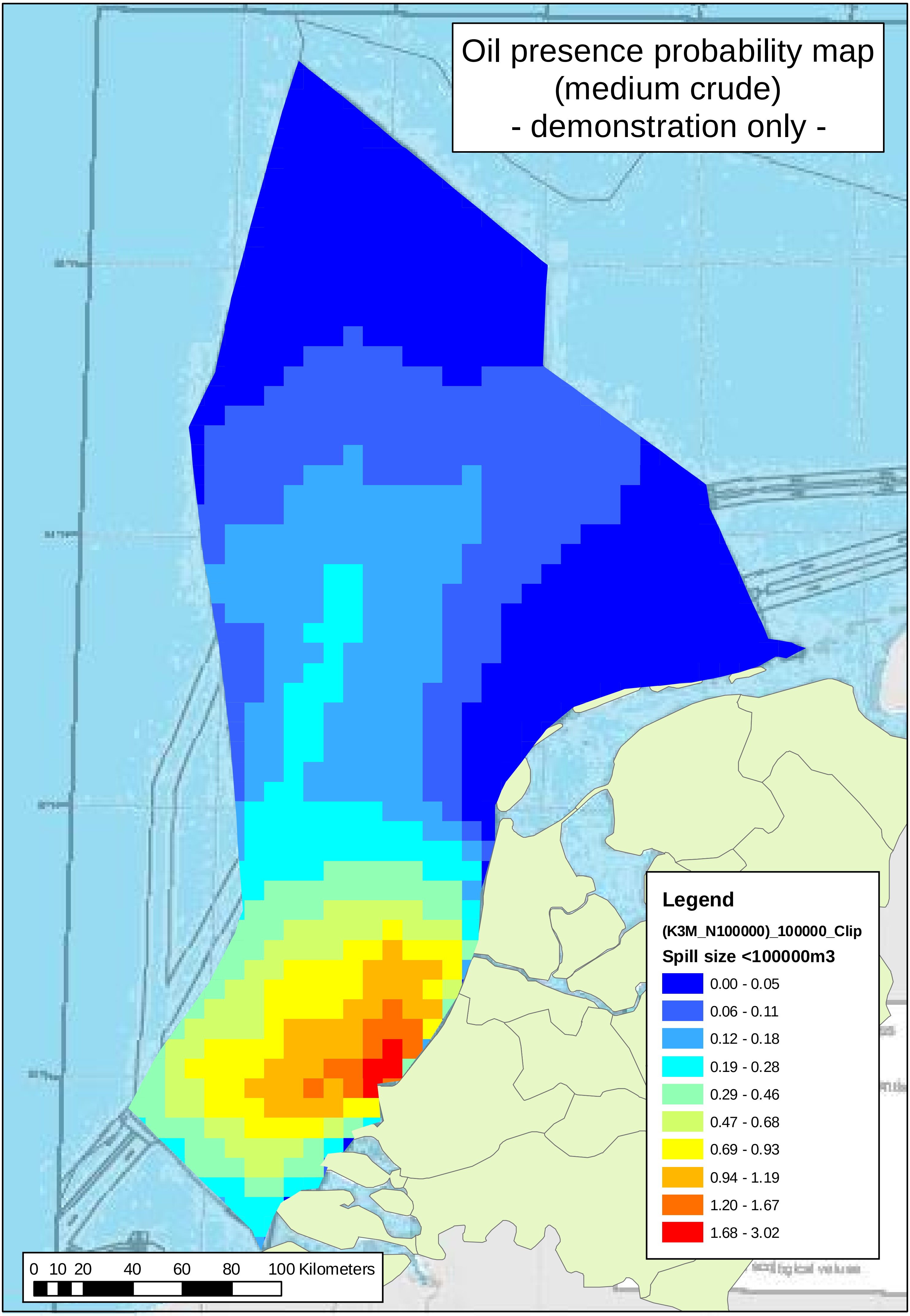
Oil presence probability map (medium crude) - demonstration only -

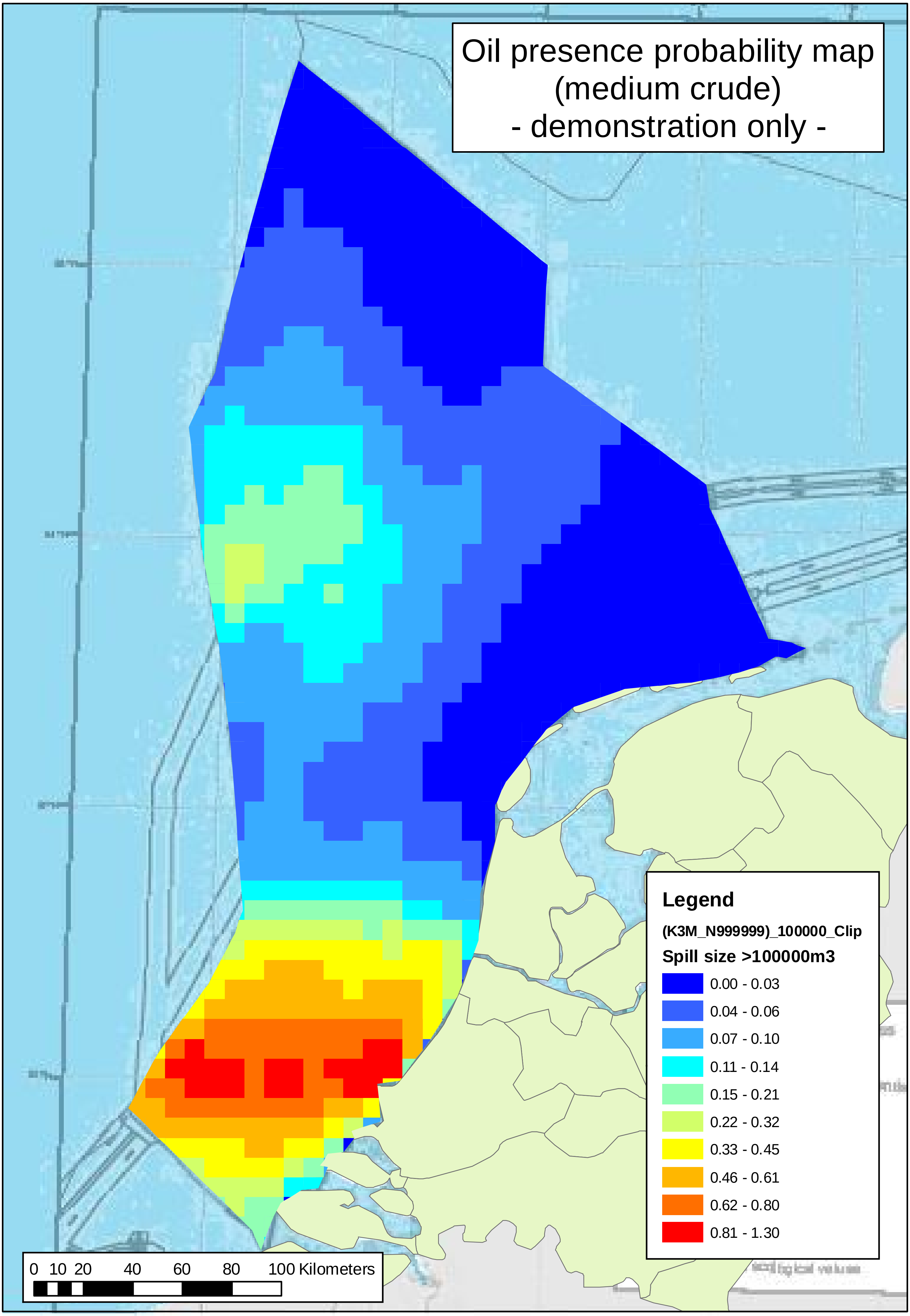

Oil presence probability map
(medium crude)
- demonstration only -
Legend
(K3M_N3000)_100000_Clip
Spill size <3000m3
0.00 - 0.06
0.07 - 0.13
0.14 - 0.21
0.22 - 0.31
0.32 - 0.44
0.45 - 0.62
0.63 - 0.87
0.88 - 1.20
1.21 - 1.53
1.54 - 2.27
0 10 20 40 60 80 100 Kilometers


Oil presence probability map
(medium crude)
- demonstration only -
Legend
(K3M_N10000)_100000_Clip
Spill size <10000m3
0.00 - 0.10
0.11 - 0.20
0.21 - 0.33
0.34 - 0.46
0.47 - 0.68
0.69 - 1.01
1.02 - 1.48
1.49 - 1.96
1.97 - 2.76
2.77 - 4.45
0 10 20 40 60 80 100 Kilometers

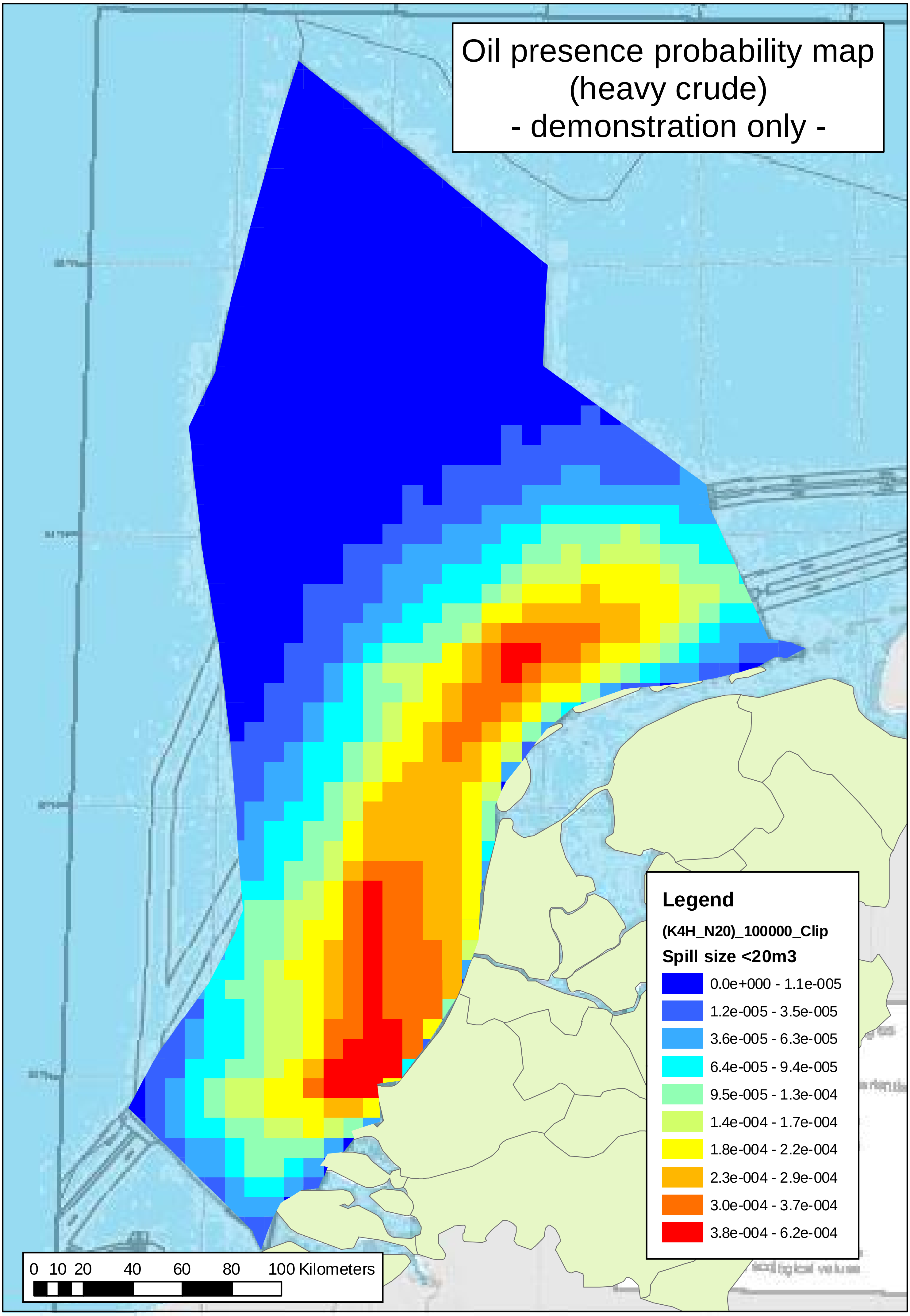


Oil presence probability map
(medium crude)
- demonstration only -

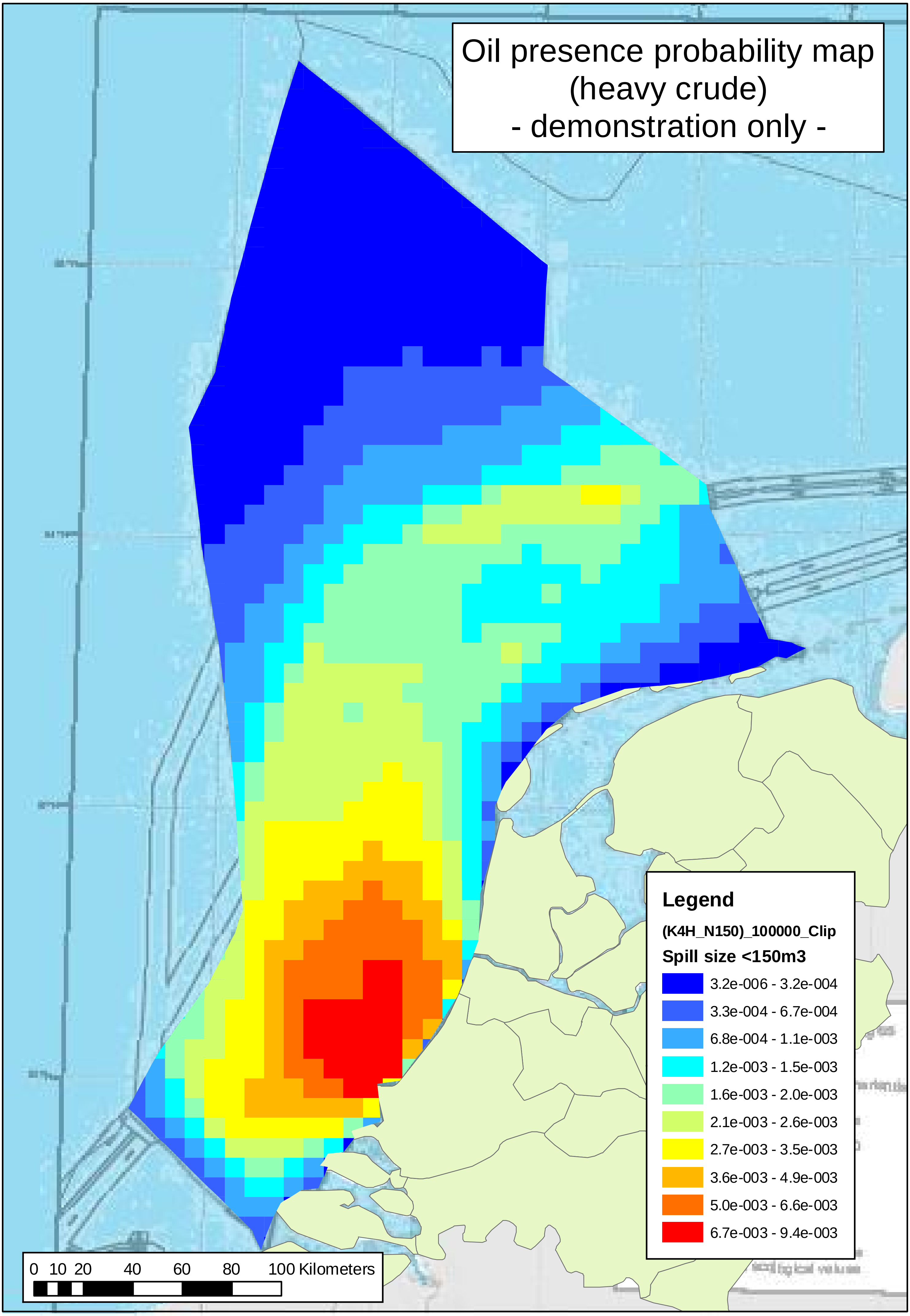

Oil presence probability map
(medium crude)
- demonstration only -
Legend
(K3M_N100000)_100000_Clip
Spill size <100000m3
0.00 - 0.05
0.06 - 0.11
0.12 - 0.18
0.19 - 0.28
0.29 - 0.46
0.47 - 0.68
0.69 - 0.93
0.94 - 1.19
1.20 - 1.67
1.68 - 3.02
0 10 20 40 60 80 100 Kilometers



Oil presence probability map
(medium crude)
- demonstration only -

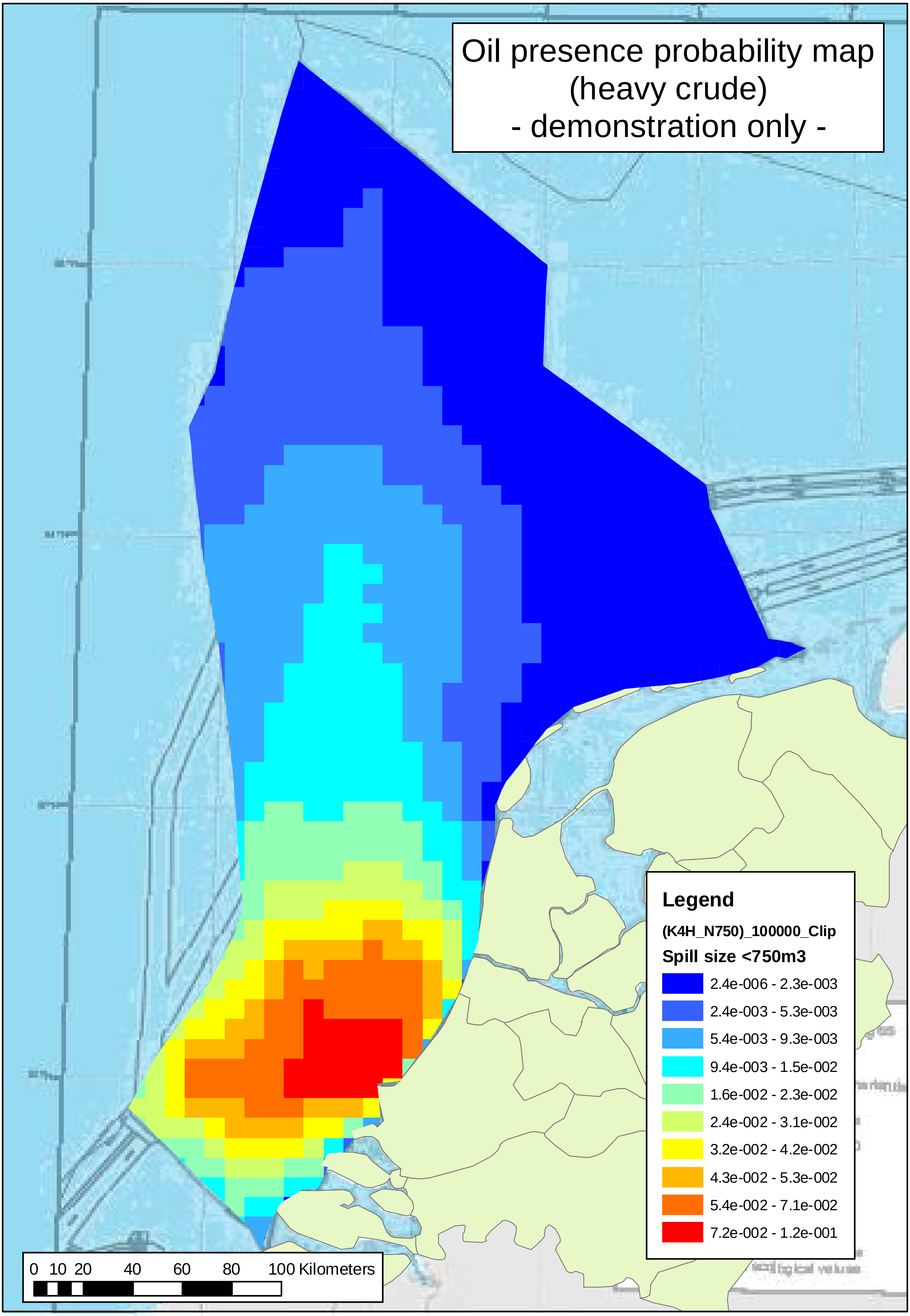


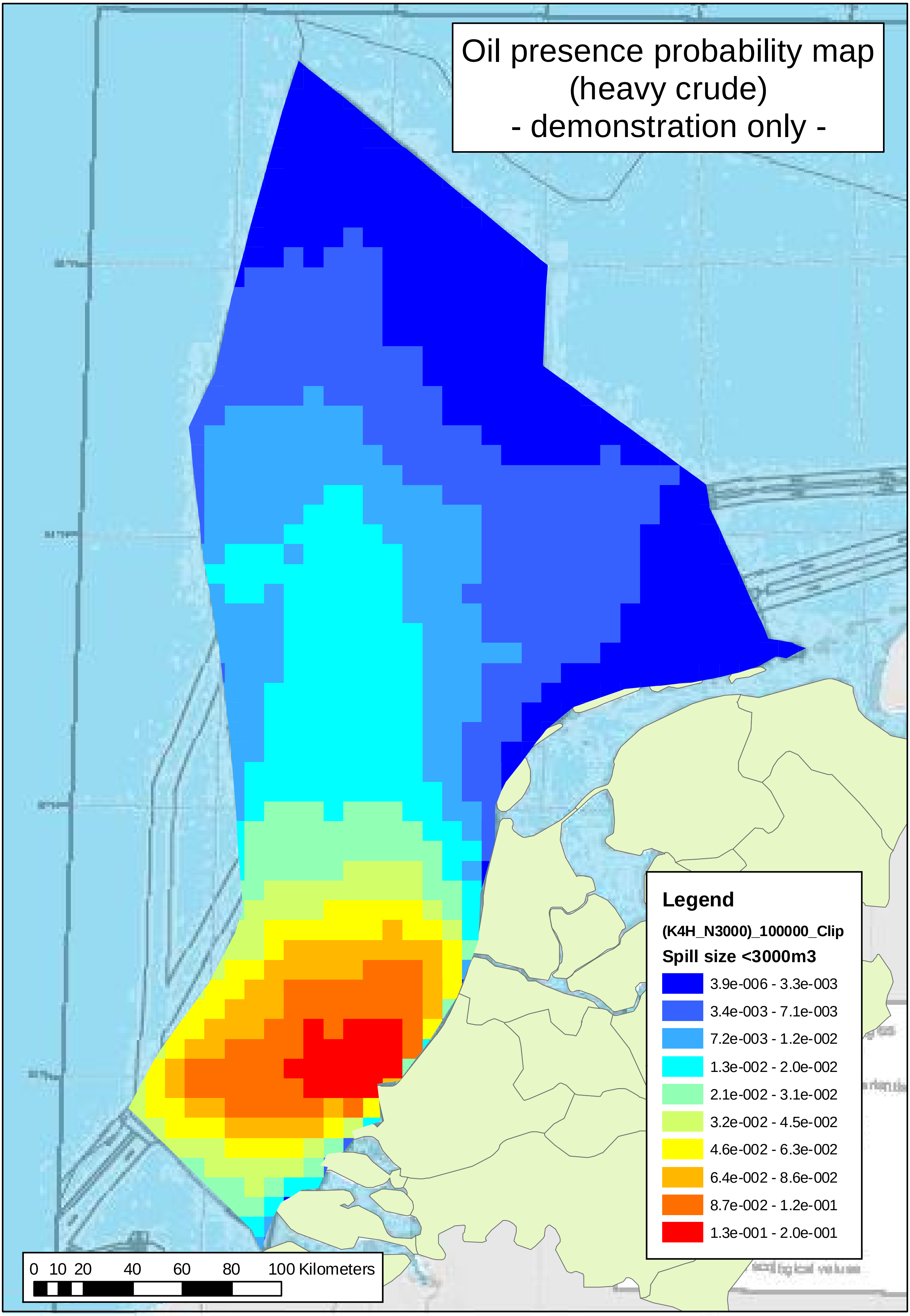
Oil presence probability map
(heavy crude)
- demonstration only -

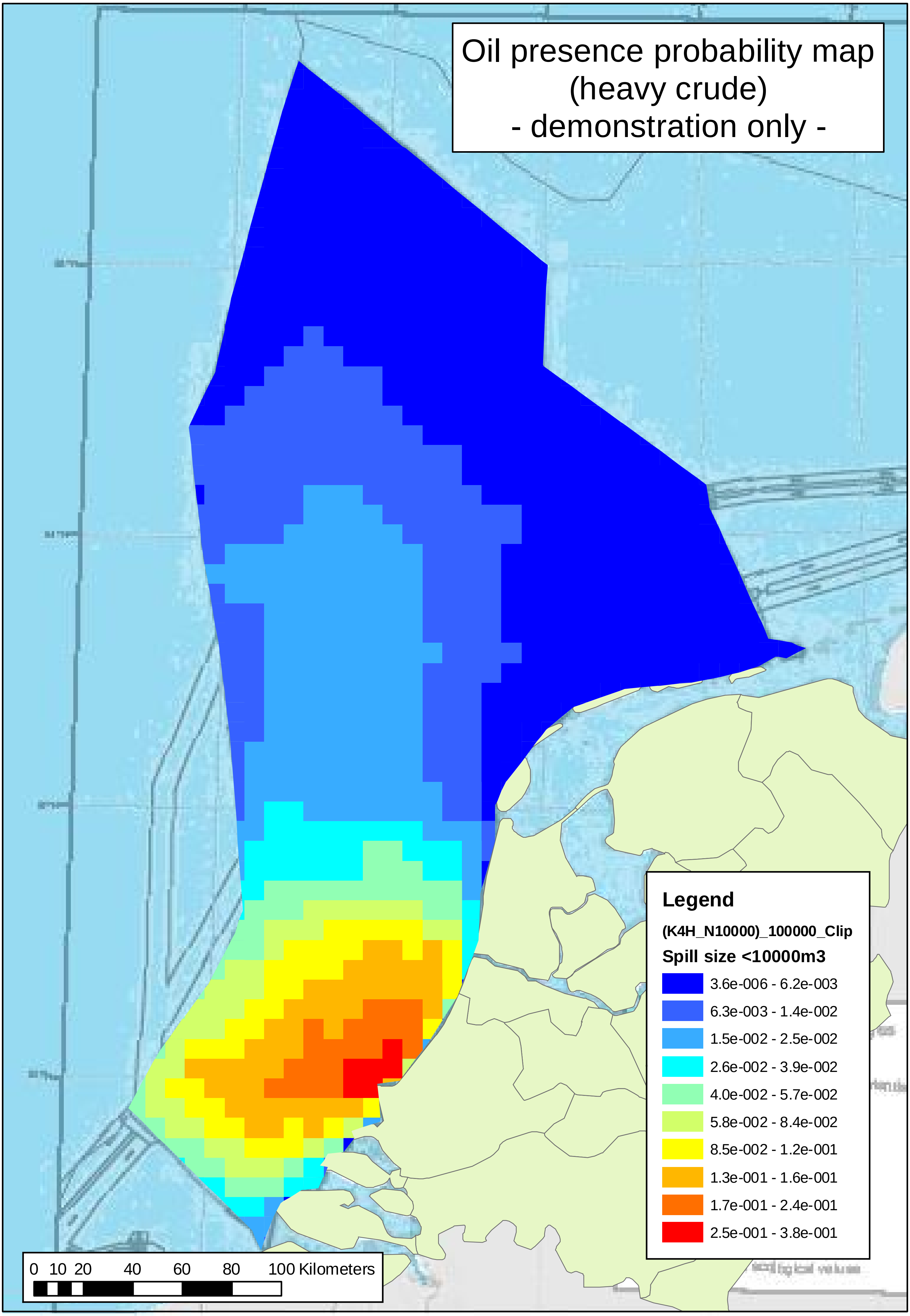


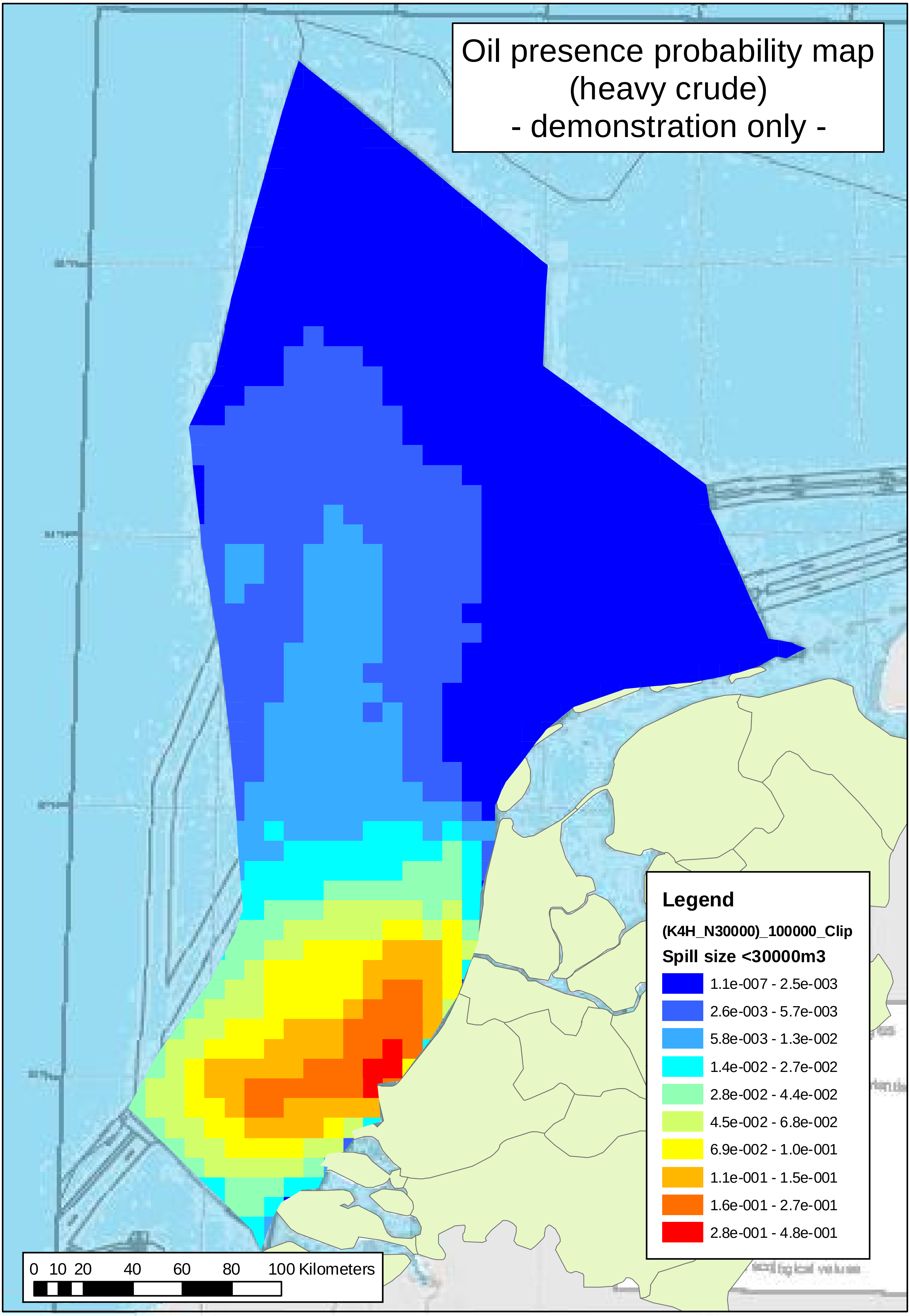
Oil presence probability map
(heavy crude)
- demonstration only -

Oil presence probability map (heavy crude) - demonstration only -

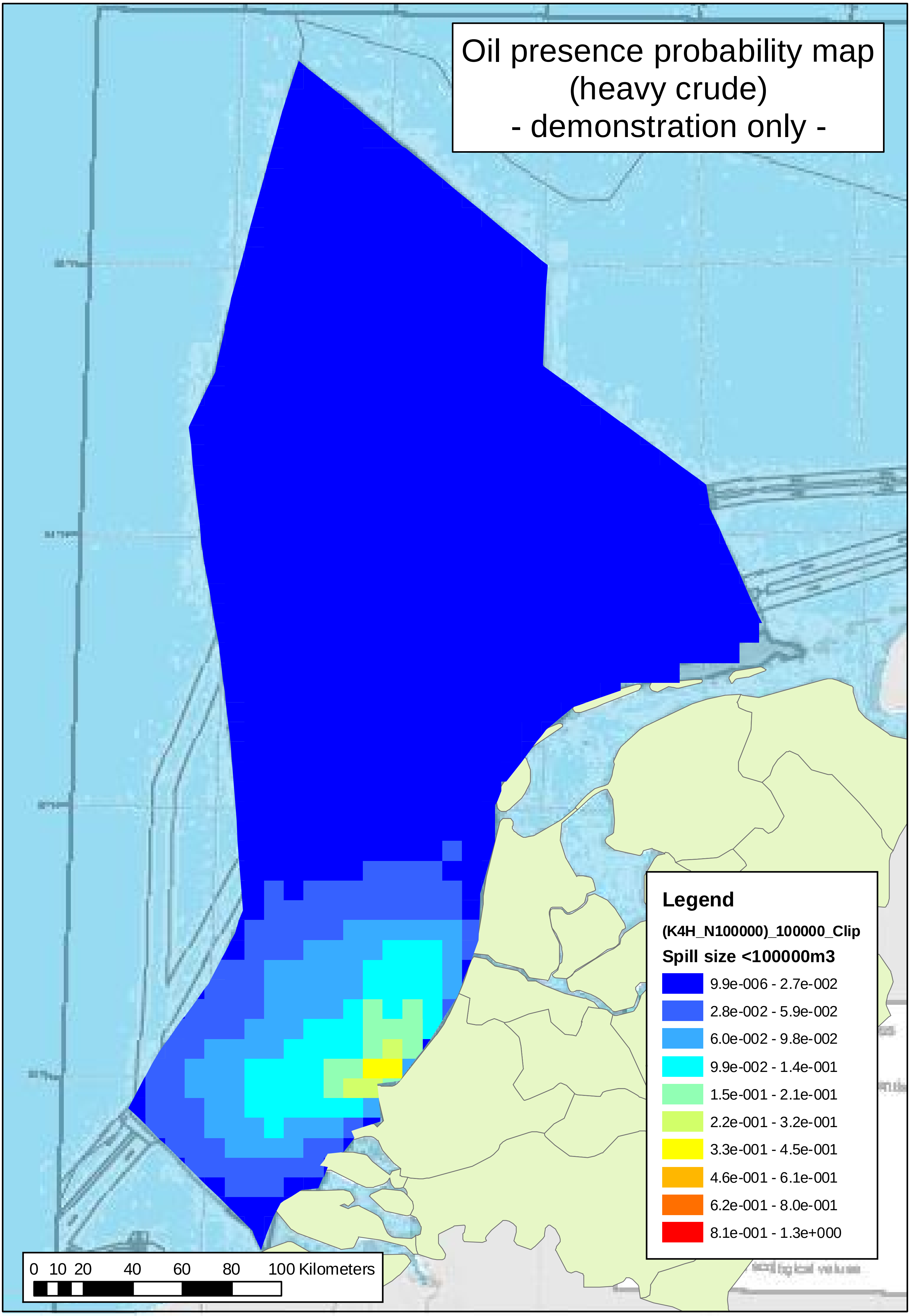


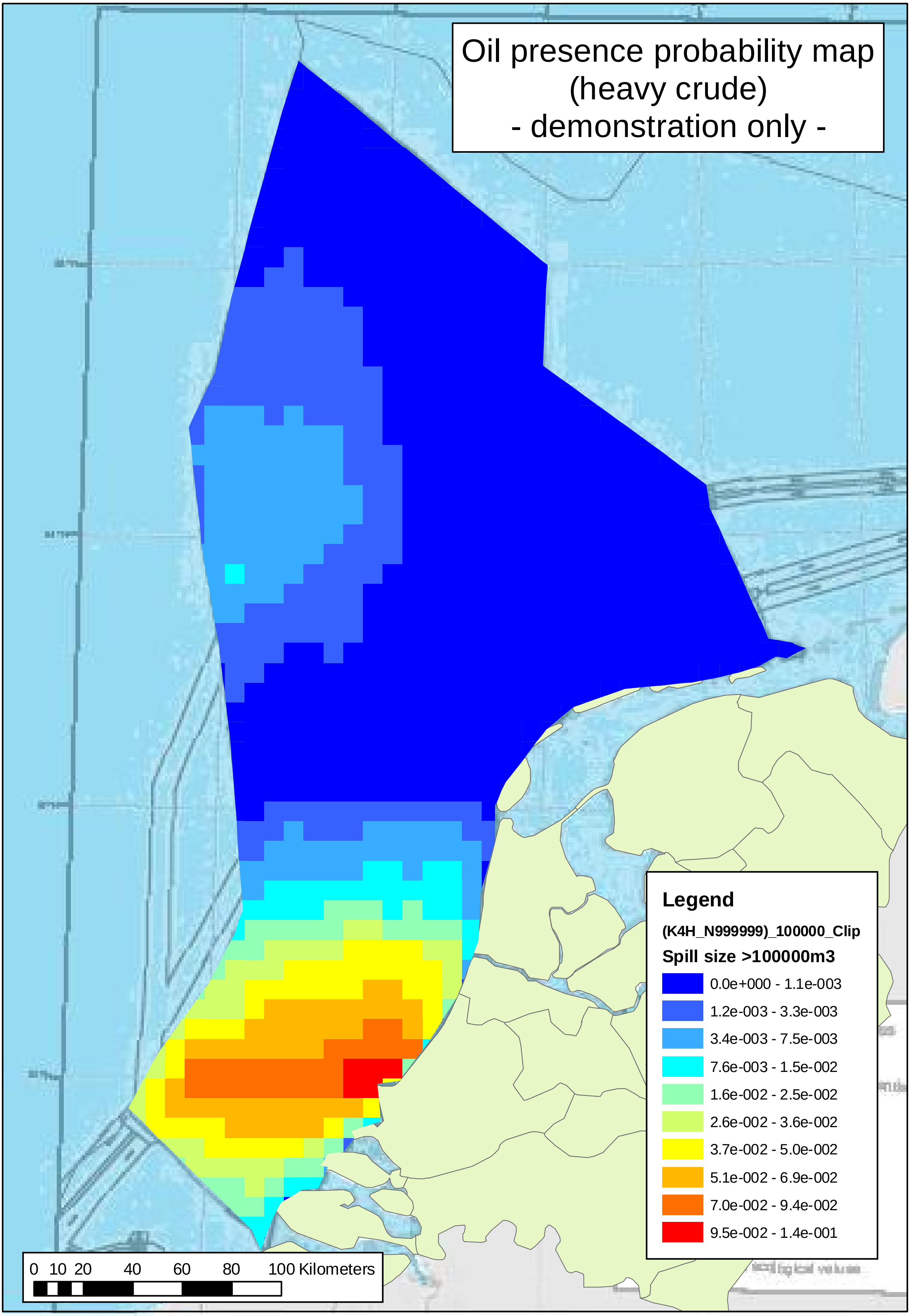

Oil presence probability map
(heavy crude)
- demonstration only -
Legend
(K4H_N3000)_100000_Clip
Spill size <3000m3
3.9e-006 - 3.3e-003
3.4e-003 - 7.1e-003
7.2e-003 - 1.2e-002
1.3e-002 - 2.0e-002
2.1e-002 - 3.1e-002
3.2e-002 - 4.5e-002
4.6e-002 - 6.3e-002
6.4e-002 - 8.6e-002
8.7e-002 - 1.2e-001
1.3e-001 - 2.0e-001
0 10 20 40 60 80 100 Kilometers


Oil presence probability map (heavy crude) - demonstration only -



Oil presence probability map (heavy crude) - demonstration only -


Oil presence probability map
(heavy crude)
- demonstration only -
Legend
(K4H_N100000)_100000_Clip
Spill size <100000m3
9.9e-006 - 2.7e-002
2.8e-002 - 5.9e-002
6.0e-002 - 9.8e-002
9.9e-002 - 1.4e-001
1.5e-001 - 2.1e-001
2.2e-001 - 3.2e-001
3.3e-001 - 4.5e-001
4.6e-001 - 6.1e-001
6.2e-001 - 8.0e-001
8.1e-001 - 1.3e+000
0 10 20 40 60 80 100 Kilometers



Oil presence probability map
(heavy crude)
- demonstration only -

Appendix B

Application considerations

Application considerations

From the experiences with the demonstration setup and application, several issues have been raised that require further discussions, development and/or should be implemented when developing a full risk assessment tool, as shown in the outline of ***Figure 1***. This demonstration of the methodology has shown the feasibility of such a full risk assessment tool. Within the framework of the Safety at Sea project, these issues are only noted here but have not been included in the present demonstration. Results of the demonstration should therefore not be seen as representing actual environmental risk from oil spills. The list of items to consider is an initial list and may be expanded when developing the full methodology at a later stage.

The most important items that will need to be considered when developing a full environmental risk tool are divided into a number of subjects:

1. *Conversion of SAMSON results to stochastic model input:*
    a. A more detailed translation of the MARIN spill probabilities as input into the stochastic model may be required. The SAMSON datafiles contain for each spill class the average spill in m^3 per year. They also contain the frequency of number of spills per year. Only the probability distribution of spills are presently used to define the stochastic modelling input. The specified spill sizes have not been used to define model input. They have only been used as weighting factors of the different oil presence probability maps. For a more detailed risk assessment, these spill sizes should be included in the stochastic modelling input.
    b. In the translation process from SAMSON to the model input, the different spill classes are used separately to define input of the stochastic particle tracking model. SAMSON provides the average outflow for a number of spill size classes for each GENO grid cell. Hence, the average spill size within on spill class varies from location to location. This is not yet implemented in the input and it is therefore not known whether the spill size variation has a significant effect on the environmental risk.
    c. Availability of shipping information has led to a restriction of the data to the NCP only. For a risk map, spills from outside the NCP affect areas inside the NCP. Hence shipping information should include data from areas outside the NCP.
2. *Delft3D-PART input:*
    a. The spills that are derived from SAMSON are defined as instantaneous spills. Where oil will affect the environment, will depend on the timing of the release and on the duration of the release. SAMSON results do not specify timing or duration. However, timing of oil spills in tidal conditions will affect the areas that are affected. If, for example, the tidal excursion would be 15km, then a release at high water and low water may result in oil patches that may be 30km apart. How the timed release will affect the general probability will need to be investigated. For a specific risk assessment, the timing and duration can be specified, but for a stochastic general risk assessment this may be more complex.
    b. At present, model particles for all sources are released at the same time. Whether or not this procedure is too restrictive for the derivation of a general risk map will need to be investigated.
    c. Since shipping data to generate spill risk are presently only availabe for the Dutch Continental Shelf (NCP), boundary effects (no data outside the Dutch Continental Shelf whilst it will have an effect on the probabilities and hence the risk inside the Dutch Continental Shelf) will need to be considered. The longer the model simulation, the larger the area that is impacted by this boundary effect.

Results in this area should not be used in the Risk Map and therefore an indication should be given as to the extent of this Boundary Affected Area.

  d. It is assumed that all wind series that are used in the model have an equal probability of occurrence. Even though each sampled wind timeseries represents an observed timeseries, the statistics of the ensemble of sampled wind timeseries will need to be consistent with general (seasonal) wind statistics. For every application this will need to be verified to avoid biased results. If particular periods (e.g. seasons) are examined then the wind sampling will also need to be taken from the representative periods. When using seasonal winds, then the hydrodynamics should also reflect the general hydrodynamic conditions for that season. In particular residual currents may vary significantly from season to season.
  e. It is noted that the wind is applied uniformly for the entire model area. There is only a temporal variation, but no spatial variation which means that the area that can be covered is limited. A spatial representation of the wind may need to be considered for a full environmental risk tool.
  f. In addition to the specific wind forcing of the stochastic model, it is noted that the present database that is used to run the stochastic model does not consider a potential correlation of oil spill incidents with weather conditions. For example, a dependence of the oil spill risk with wind speed (e.g. storm conditions) or presence of fog is not accounted for. The feasibility of including this or other correlations into the risk assessment tool will need to be evaluated. It is not considered in this project.

3. *Delft3D-PART output:*
  a. The particle distributions for every output timestep are mapped onto a grid with a predefined, user-selected, grid resolution. The GENO grid has a 8*8km grid size, which is the grid used by VONOVI (VerkeersOnderzoek NOordzee Visuele Identificatie) flights (Koldenhof and van der Tak, 2003), whilst the V-maps use a 5*5 km grid size. The resolution of the V-map is based on the premise that "…too much detail may give a wrong idea of accuracy, whilst too little detail would make the maps useless.." (Offringa and Lahr,2006). Grid resolution will affect the results, since the probability that oil will be present will be smaller for smaller grid cells. Large grid cells may aggregate the results too much. The present output grid resolution of the stochastic modelling is 5*5km since this is also used for the generation of the V-maps. A more formal definition of the optimum grid resolution will need to be carried out.
  b. An output frequency is required when calculating the spatial probabilities. This may be limited by the size of the output files and/or the resolution of the output grid. The timestep should be at least such that a particle cannot "skip" an output grid cell between two timesteps. Generally output is generated every hour or 30 minutes. If, for example, the drift of a particle is about 10 cm/s, and the output grid size is 1000m then a 2 hour timestep for the output would be the minimum.
  c. The length of the simulation period that is analysed for the generation of the spatial probability and over which period, after particle release, the analysis will be carried out (from release time to n days, or from n days to m days, etc.) will affect the results. It appears logical to start the output analysis directly after release, but when to stop the model simulation is less obvious. Criteria on which to base a simulation period on will need to be defined. This may be, for example, based on the persistence of the oil, or maximum response times to combat pollution or the aforementioned boundary effects, if present. For example for a diesel spill, the simulation may only need to cover a few days because diesel will evaporate within a few days.
  d. Oil presence probabilities are derived for surface floating oil only. Dispersed and beached oil (or oil on sediments) are not included, although the oil exposure

    manifests itself will have an enviromental effect. In order to be able to assess this, oil processes will need to be included.

4. *Delft3D-PART oil processes*
    a. In the present setup of the stochastic model, actual spill amounts are not used, only probabilities are applied. This means that the model calculates the advection of the probabilities and not the actual substances. Hence, oil processes cannot be implemented when generating the general oil presence probability map. But the fate of the oil will need to be considered when deriving risk. Options on how to incorporate the fate of the oil will need to be investigated at a later stage.
    b. Physical and chemical properties of the oil type have not been used at this stage of the development. To assess the environmental effects, the fate of oil is an important factor. To make a distinction between, for example, surface floating oil, dispersed oil (into the water column) and evaporation will provide the means to make a more detailed assessment of the risk to the ecology. For a complete risk assessment system, the properties and effects of spill volumes will need to be included in the future.
    c. There may be a number of options in which to incorporate the oil processes in the risk assessment. The fate of the oil may, for example, be investigated after the stochastic modelling, as a post-processing excercise using an oil budget model. The oil budget provides a general overiew of the fate of oil in terms of amount floating on the water's surface, amount evaporated, dispersed, or adsorped to sediments and other oil characteristics. The use of such a oil budget model requires time related indicators that will need to be derived from the stochastic modelling. The results of an oil budget model would, in combination with the oil presence probability, lead to an exposure that is linked to the type of oil, size of the oil spill, and fate of the oil. The significance of the dependency of the oil will need to be considered at a later stage.
    d. The fate of the oil will depend on the size of the spill, although it is not clear to what extent this is will affect the oil budget for a given case. If it is assumed that the size of the spill does not significantly affect the processes, then this would mean that it would not be necessary to recalculate the oil budget for the different spill size classes. Instead, the results can be scaled according to the size class. Only if the oil type is different, then the oil budget will also change. For a specific risk assessment – method(2) – (focussing on most sensitive areas), oil processes can be more easily included.
    e. The number of particles required for a stochastic modelling application is based on the number of source locations and the number of windseries (see Section 3.2.2). Thus, with 1000 discharge locations (GENO grid) and 500 wind time series, 500,000 particles will be required. At present, however, the model does not include horizontal dispersion. To represent horizontal dispersion at least 10 times the given number will be needed. This will affect performance of the model (run times, memory requirements) and there is a maximum number of particles that can be used (which is hardware dependent). It is not know to what extent the horizontal dispersion will affect calculated oil presence probabilities and whether the introduction of horizontal dispersion into the model simulations is required. The sensitivity of the results to horizontal dispersion will, therefore, need to be investigated.
    f. At present, mitigating or oil combatting measures, such as recovering oil at sea, or the use of dispersants, are not accounted for. If dispersants, for example, are used or intended, then this may lead to a different risk to the environment. This should be included when generating a risk map. In particular for specific risk assessments, options of the use of spill response will need to be included in the tool.

5. *Generation of risk*
    a. The manner in which the information from the stochastic modelling is processed and presented is essential in developing an understanding of the main issues and is therefore important in supporting the decision making processes. Different options will need to be investigated in collaboration with those organisations involved in these decision making processes.
    b. The method should be a generic one. So it must be possible to apply this methodology on any coastal sea in the EU or outside.
    c. Inclusion of time related information in the presentation of the results will need to be investigated. This is related to processes and fate of oil as a function of time. Also ecological vulnerability varies throughout the seasons. The use of additional time-related indicators will need to be examined. The seasonal influence on processes, oil characteristics, weather conditions, hydrodynamics will affect the oucome of the risk analysis, which means that when seasonal variations are significant, then these variations will need to be taken into account. Thus this would lead to seasonal dependent oil presence probability maps (i.e. seasonal P-maps). The implication of this is also that if traffic varies throughout the seasons, then this would require seasonal spill probabilities
    d. The manner in which the spatial oil presence probability is linked with V-maps will need to be specified in more detail. At present the V-maps do not take account of exposure time or concentration. It appears logical that the longer an area is exposed to oil or the higher the oil concentration, the greater the actual environmental damage (at least for some elements of the ecosystem).
    e. It may be possible to link the stress factors that are used to derive the V-maps with detailed results of the oil model. The model budget will provide the relative presence of evaporated, floating, dispersed oil. This, in combination with the general vulnerability map, the oil presence probability and the relative importance of these types of stresses (on which the V-map is partly based) may be seen as contributing to risk. Hence, this type of link will need to be investigated.
    f. In this project hydrodynamics are generated to represent annual average conditions. When deriving time varying risk (every two months) to reflect the time/seasonal variation of the V-map then the hydrodynamic database will need to be expanded to represent average conditions for these 2-month preriods.
    g. Grid resolution can affect results and a description of method or criteria on the output grid will be required.
    h. For an objective assessment of risk, indicators of risk will be needed. Risk may be presented as a quantitative risk value, with fixed criteria on how to define high, medium and low risk. On the other hand, qualitative and relative risk indicators may also be developed. The manner in which the risk distribution is presented will depend on the risk perception of the user and requires further and detailed analysis of what the user's need.
    i. Contingency planning is aimed at reducing the risk to the environment. Risk maps should therefore also account for the reduction in risk from contingency plans. Risk mapping may then aid the development of more efficient contingency planning.

Of the issues that are mentioned, the most important ones that would need to be considered on a relatively short timescale if a robust risk assessment tool is to be developed are:

- introduction of oil processes – this is a potential complex issue within the stochastic modelling;
- timing and duration of risk releases – whether or not this is a significant factor can relatively easily be investigate through sensitivity studies. If discharge times and durations are to vary

within one application, then sifgnicant changes to the presently available software may be needed.

- more detailed speficiation of the link of the oil presence probabilities with the V-maps.

The other items will need to be addressed in the more medium term and further analysis will indicate whether they are essential or whether the sensitivity of the risk maps to these items is relatively small.