Technical Note

Update to dilution factors for the UK risk-based approach to the management of produce water discharges from offshore installations.

November 2020

Acknowledgements

The document has been prepared by Genesis Oil and Gas Consultants (Genesis) with input from the Department for Business, Energy and Industrial Strategy (BEIS) and the Centre for Environment Fisheries and Aquaculture Science (CEFAS).

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Contents

Abbreviations

Abbreviations	Definitions
'	Minute (coordinates)
"	Second (coordinates)
<	Less than
>	More than
°	Degrees
°C	Degrees centigrade
BEIS	Department for Business, Energy & Industrial Strategy
CNS	Central North Sea
DECC	The Department for Energy and Climate Change
DF	Dilution Factor
DREAM	Dose-related Risk and Effects Assessment Model
E	East
ED	European Datum
g	Gram
kg	Kilogram
m	Metre
$m^3 yr^{-1}$	Metre cubed per year
min	Minute (time)
N	North
n	Sample size
NNS	Northern North Sea

Abbreviations	**Definitions**
NOS	Naturally Occurring Substance
PBT	Persistent, Bio-accumulative and Toxic
PEC	Predicted Environmental Concentration
PNEC	Predicted No Effect Concentration
ppm	Parts per million
PW	Produced Water
RBA	Risk Based Approach
s	Second (time)
SNS	Southern North Sea
UK	United Kingdom
UTM	Universal Transverse Mercator
WET	Whole Effluent Testing
yr	Year

Introduction

Risk Based Assessment of Produced Water

OSPAR Recommendation 2012/5 required Contracting Parties to have implemented a Risk Based Approach (RBA) for the management of Produced Water (PW) discharges from offshore installations by 31 December 2018. The Department for Business Energy and Industrial Strategy (BEIS) is responsible for the implementation of the UK RBA programme, which required all offshore operators in the North Sea that have a permit to discharge PW (or a permit with the contingency to discharge PW) to assess the risks associated with the PW discharge.

The UK RBA methodology comprised a four-tier approach:

- Tier 1: Persistent, Bio-accumulative and Toxic (PBT) screening. This considers the extent to which a PW discharge is PBT, based on the results of toxicity testing of the PW effluent (i.e. Whole Effluent Testing (WET)).
- Tier 2: Determination of whole effluent Predicted Environmental Concentration (PEC) to Predicted No Effect Concentration (PNEC) ratios (i.e. PEC:PNEC ratio) using a generic Dilution Factor (DF). Tier 2 involves screening out PW discharges if the whole effluent PEC:PNEC ratio at 500 m from the discharge point is ≤ 1.
- Tier 3: Determination of the whole effluent PEC:PNEC ratio using by modelling the dispersion of the whole effluent using the PNEC from WET toxicity data.
- Tier 4: Determination of the PEC:PNEC ratio by modelling both naturally occurring substances (NOS), based on biannual sampling, and added chemicals in the PW, based on current chemical permits for the installation.

For the implementation of the Risk Based Approach, operators were required to undertake all assessment tiers (Tier 1 was optional), in order to provide a better understanding of risks associated with PW discharges. BEIS have reviewed the results of all the RBAs reports submitted during the implementation cycle informing a refinement of the UK RBA process and guidance. The purpose of this report is to assess the dilution factors at Tier 2 used during the implementation cycled.

Dilution Factors

Currently Tier 2 involves screening out PW discharges if the whole effluent PEC:PNEC ≤ 1 at 500 m from the discharge point, using a generic DF derived from the RBA trial (DECC, 2014; Table 1). The DFs were based on the modelling of an inert tracer using a minimum DF at 500 m (i.e. based on the maximum concentration of a contaminant at any point in the water column at any point in time). This approach is very conservative as the maximum concentration may only exist for a very short period of time in a specific location within the water column. The number of installations used to derive the DFs was relatively small (thirteen installations) but was the only data available at that time.

The Marine Environmental Modelling Workbench (MEMW) Dose-related Risk and Effects Assessment Model (DREAM) developed by Sintef was used for the modelling.

Table 1: DFs used in RBA guidelines (DECC, 2014)

Water depth (m)	**Annual PW discharge volume (m^3 yr^{-1})**			
	< 100,000	**100,000–1,000,000**	**1,000,000–8,000,000**	**> 8,000,000**
< 50	10,000	1,000	400	100
50–125	10,000	4,000	400	100
> 125	20,000	8,000	400	100

Following the results of the RBA implementation cycle, BEIS had concerns that the existing DFs were more conservative than was necessary for Tier 2, resulting in a number of installations having a PEC:PNEC ratio > 1 at Tier 2 even though subsequent modelling at Tier 3 and Tier 4 showed the PW discharge as having a low environmental risk. These concerns were particularly related to those installations with a PW discharge < 100,000 m^3 yr^{-1}.

Scope of Work

BEIS commissioned Genesis Oil and Gas Consultants (Genesis) to review and update the Tier 2 table of DFs, focussing in particular on discharges of less than 100,000 m^3 yr^{-1}. The objective was for the revised table to be included in an update to the UK RBA guidelines (to be issued in 2020).

Genesis undertook a factorial modelling exercise in which two discharge locations, four discharge depths and three discharge rates were modelled using an inert and neutrally buoyant chemical. As previously stated the DREAM model was used. Using theoretical discharges rather than specific operational assets allows for a more objective assessment. Using operational assets makes it difficult to isolate the effects of depth and discharge rate because other variables, such as location (and therefore different metocean data), type of installation (gas/oil/condensate), depth of discharge, etc, may also impact the DF.

This report presents:

- The methods used to calculate DFs and undertake the data analysis;
- The results of DREAM modelling;
- Statistical analysis of those results; and
- A proposed revised table of DFs for use in the RBA guidelines.

Methodology

Discharge Location, Depth and Rate

- Dilution of pollutants at 500 m from a theoretical discharge was modelled using DREAM. Two discharge locations, four discharge depths (greatest depth differed between the two locations chosen) and three discharge rates were tested to evaluate the effects of discharge location, resulting in 18 simulations. A summary of the values tested is listed here and a full list of the 18 simulations undertaken can be found in (Table 3):
- Discharge locations (see Figure 2):
  - Central North Sea (CNS): 56°00’00”N; 02°00’00”E; Seabed depth = 84 m
  - Northern North Sea (NNS): 61°30’00”N; 01°00’00”E; Seabed depth = 186 m
- Discharge depths:
  - 10 m
  - 50 m
  - 74 m (10 m above seabed; CNS only)
  - 130 m (NNS only)
- Discharge rates:
  - 25,000 m^3 yr^{-1} (68.446 m^3 day^{-1})
  - 75,000 m^3 yr^{-1} (205.339 m^3 day^{-1})
  - 125,000 m^3 yr^{-1} (342.231 m^3 day^{-1})

Two discharge locations have been selected to verify whether there are differences in DF as a result of different metocean conditions, prevailing in the CNS and the NNS. Ideally, additional locations within each region would also have been modelled, however, given the number of other variables to be tested and in order to keep the number of model runs manageable, this study was restricted to two locations. The Southern North Sea (SNS) was excluded because of the limited water depth range and because there was not a big range in PW discharge rates, with the majority of installations having a low PW discharge rate with few added offshore chemicals.

The discharge depths were selected to represent discharges near the sea surface, mid-depth and near the seabed. Different values were used for the deepest depth in the CNS and NNS because of the greater depths reached in the NNS.

The three discharge rates were selected to cover a range of values below 100,000 m^3 yr^{-1} and slightly above 100,000 m^3 yr^{-1} in order to have some overlap with the existing DFs table (DECC, 2014).

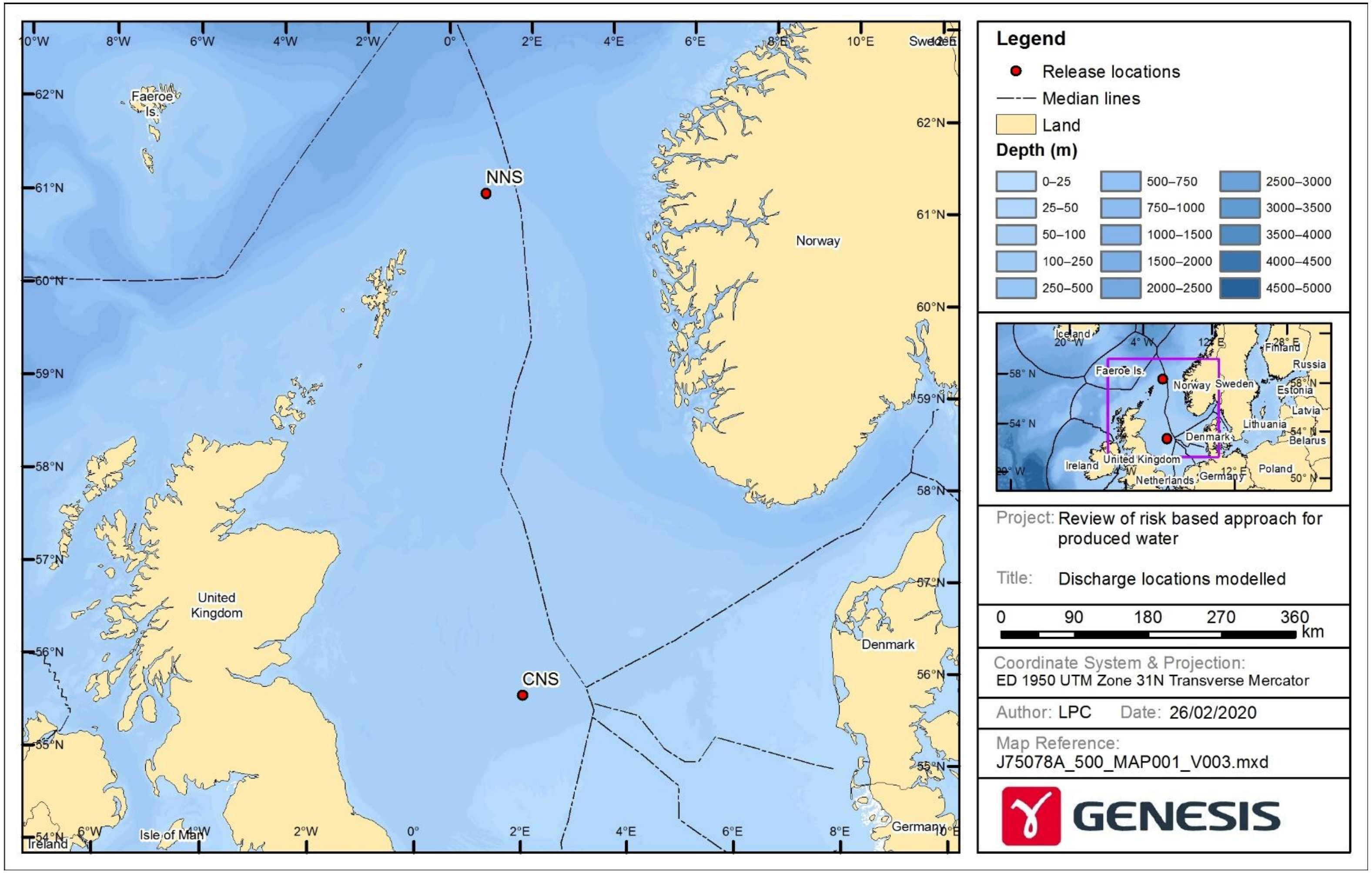

Figure 1: Discharge locations modelled.

Metocean and Bathymetric data

Modelling was conducted over 31 days, using metocean data for May 1990. The metocean data used comprises the three-dimensional currents and two-dimensional winds dataset developed by the Norwegian Meteorological Office and widely used for the prediction of PW plumes in UK and Norwegian waters. May is the month normally selected (and as recommended by the RBA guidelines) for RBA modelling as it typically has calm metocean conditions and therefore represents a likely worst case for dilution.

The MEMW default bathymetry was used (Sea Topo 8.2). Water surface, bottom temperatures, and salinity were selected as 10°C, 4°C and 35 g kg^{-1}, respectively (default values in MEMW).

Model Configuration

Modelling parameters other than those listed in the 'Discharge Location, Depth and Rate' Section were kept constant and are summarised below (Table 2).

Table 2: Model input parameters

Type	Parameter	Value	Comment
Release information	Tracer	NA	An inert and neutrally buoyant tracer was used with a concentration of 1,000 ppm since the focus of the study was dilution without chemical or biological interactions.
	Discharge duration (days)	31	Sufficient for plume stabilisation
	Salinity of produced water (g kg^{-1})	84.8	Average of values reported in RBA reports
	Temperature (°C)	41.3	Average of values reported in RBA reports
	Oxygen content	0	NA
	Release diameter (m)	0.5	Average of values reported in RBA reports
Physical parameters	Liquid/solid particles	30,000	Maximum available
	Dissolved particles	30,000	Maximum available
	Surface grid resolution (cell size)	10 m × 10 m	NA
	Depth grid resolution	5 m intervals	NA
	Output interval (min)	10	NA
	Time step (s)	30	NA

Data Analysis

Model Outputs

Concentrations

The model calculates concentration of the chemical over time. Maximum and median concentrations 500 m from the discharge point were calculated using a Python script and used for subsequent statistical analysis.

Maximum concentrations were defined as the maximum concentration over depth and time around the 500 m perimeter from the release location.

Median concentrations were derived in three stages:

Identification of the maximum concentration over depth for each time point for each 2D (x,y) quadrant of the model domain (referred to as the cumulative concentration);

Determination of the median concentration of the cumulative concentration for each 2D quadrant over time; and

Determination of the median concentration of all 2D quadrants at 500 m.

Derivation of Dilution Factors

The maximum and median concentration at 500 m were then converted to a DF using the equation below:

$$\text{DF} = \frac{10^6}{[\text{Tracer}]_{x,y,500\text{m}}};$$

Where [Tracer]x,y,500m (ppb) is the concentration of chemical at 500 m from the discharge location in the horizontal plane at location (x,y) and x and y are the longitude and latitude, respectively. In this case the chemical concentration used is either the maximum or the median concentration. The maximum concentration gives a minimum DF. Since the release concentration is 1,000 ppm (1,000,000 ppb), the whole discharge would be 1,000,000 ppb.

Statistical Analysis

Statistical analysis of the DFs (both minimum and median) was carried out in R (R Core Team, 2019). Preliminary data exploration was undertaken to establish correlations and variability within the data. DF (as minimum and as median values) was initially modelled as a function of discharge rate, depth and location using an analysis of variance modelling approach. The model was optimised in a step-wise manner by removal of non-significant terms of higher order to those of lower order (Crawley, 2013). Parametric assumptions of homogeneity of variance and normality were assessed visually (Figures 27 and 28 in Appendix B).

Results and Discussion

Dilution Factors

DFs were derived from DREAM outputs. An example of DREAM minimum DF output is shown below (Figure 3). Outputs from all 18 simulations are given in Appendix A and summarised in Table 3.

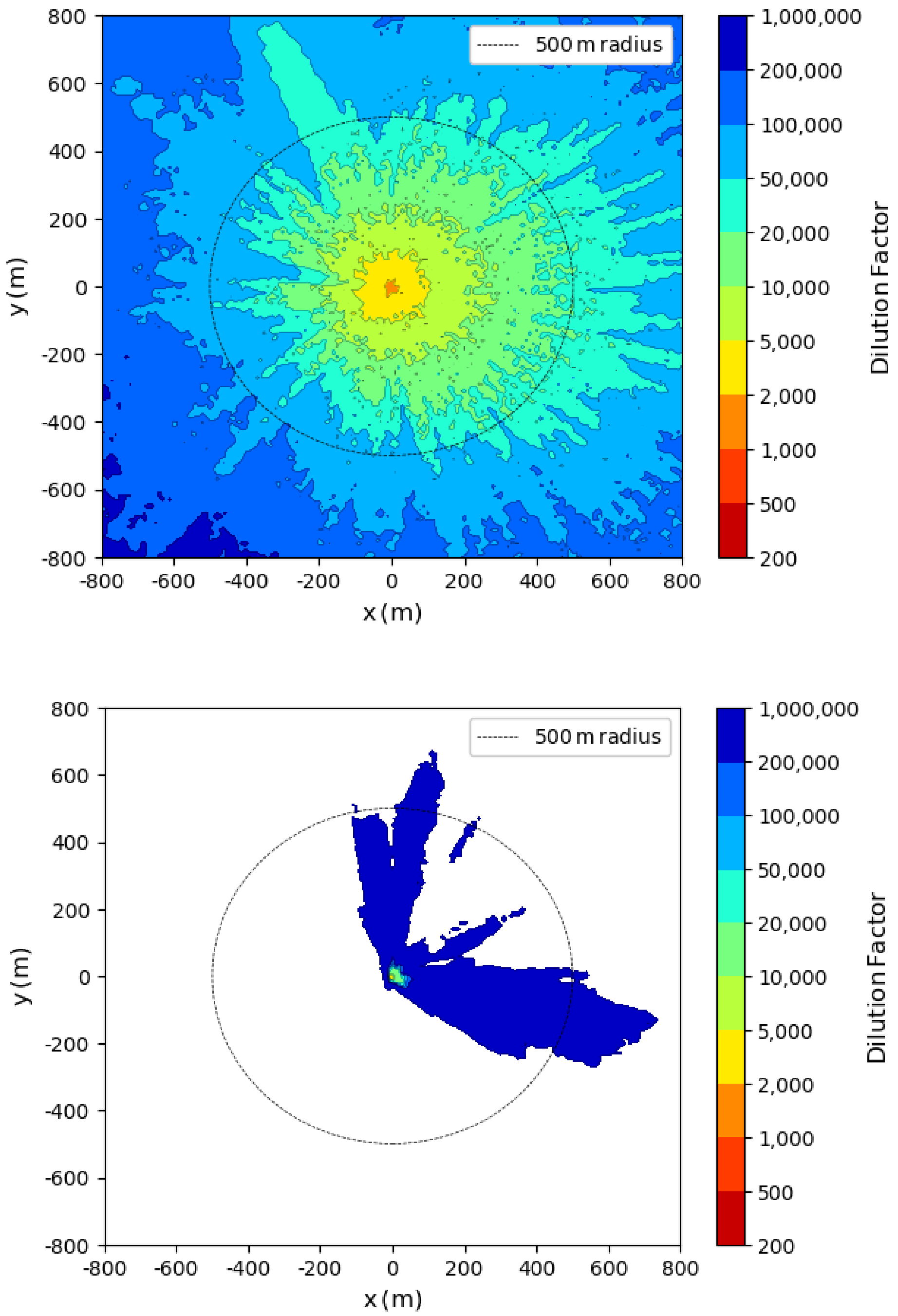

Figure 2: Minimum (top) and median (bottom) gridded DF for the simulation in the NNS at 10 m deep and a discharge rate of 75,000 m^3 yr

Table 3: Summary of DFs derived from modelling results

Simulation number	Location	Discharge depth (m)	Discharge rate (m^3 yr^{-1})	Minimum DF	Median DF
1	CNS	10	25,000	28,195.08	8,729,079.06
2	CNS	10	75,000	14,457.27	2,060,740.94
3	CNS	10	125,000	10,460.11	1,138,185.50
4	CNS	50	25,000	18,437.81	3,381,649.22
5	CNS	50	75,000	6,992.27	1,051,850.34
6	CNS	50	125,000	4,329.05	675,521.18
7	CNS	74	25,000	8,941.54	2,081,948.26
8	CNS	74	75,000	3,262.79	751,279.66
9	CNS	74	125,000	2,168.25	450,187.59
10	NNS	10	25,000	22,730.64	5,534,296.75
11	NNS	10	75,000	14,749.95	2,003,389.83
12	NNS	10	125,000	10,353.96	1,285,445.69
13	NNS	50	25,000	22,775.26	4,703,213.48
14	NNS	50	75,000	13,867.70	1,939,497.20
15	NNS	50	125,000	8,500.44	931,541.27
16	NNS	130	25,000	17,224.54	2,324,322.83
17	NNS	130	75,000	15,658.33	772,387.30
18	NNS	130	125,000	9,534.73	385,887.36

Data Analysis

The results suggest that an increase in discharge rate results in a decrease in DF for both minimum and median values (see Table 3). This aligns with the previous RBA guideline table with DFs of 10,000 and 20,000 for discharges ≤ 100,000 m^3 yr^{-1} (Table 1).This modelling exercise has resulted in minimum DFs of ~15,000 and ~10,000 for discharges of 75,000 and 125,000 m^3 yr^{-1}, respectively (Figure 3).

Figure 3 and Figure 4 show the results for minimum and median DF for each of the modelling scenarios.

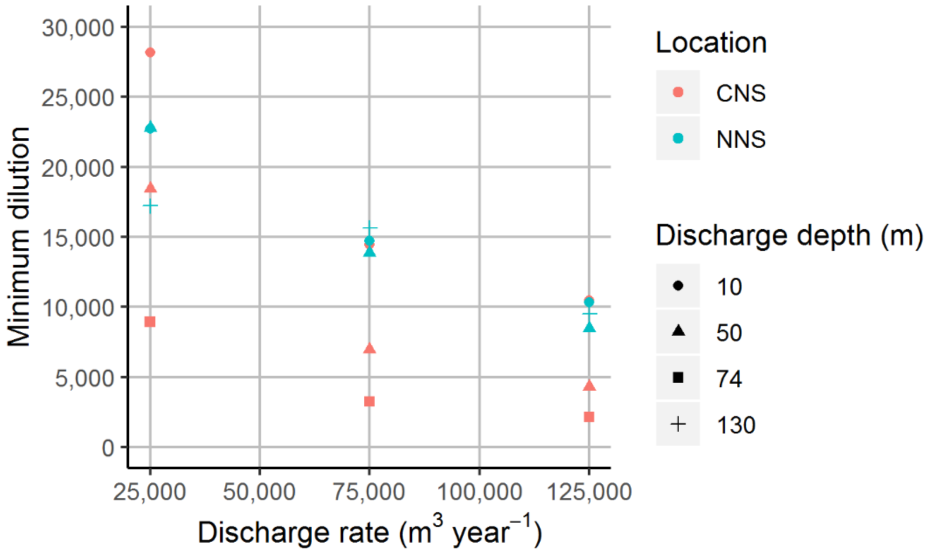

Figure 3: Minimum DFs by discharge rate, location and depth

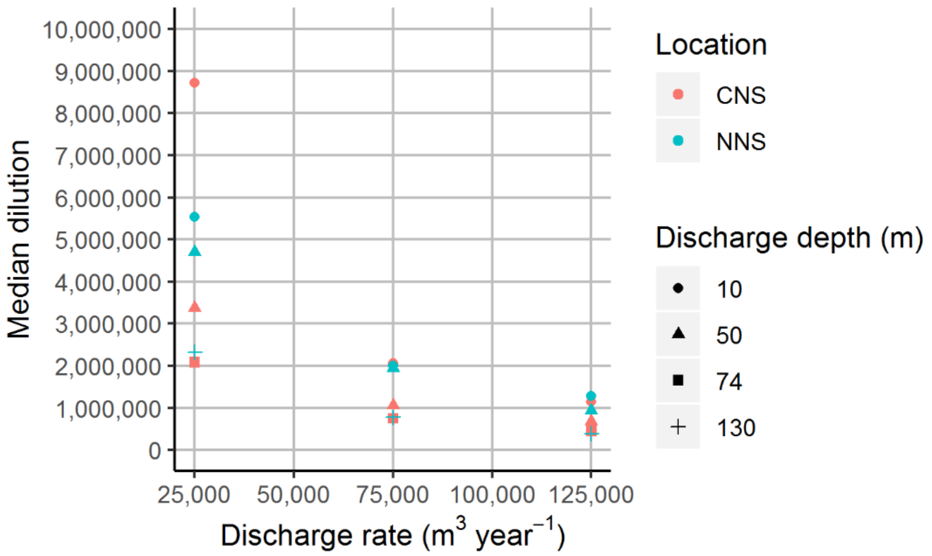

Figure 4: Median DFs by discharge rate, location and depth

DFs resulting from simulations that were close to the seabed (CNS at 50 m and 74 m discharge depths, resulting in a 34 m and 10 m distance from the seabed, respectively) tended to deviate from the minimum DFs recorded for other simulations (Figure 3). This is likely to be due to the proximity of the discharge location to the seabed in the CNS location. The produced water discharge modelled here sinks because its salinity (84.8 g kg^{-1}) is greater than that of the surrounding seawater (35 g kg^{-1}) and therefore is denser. It has less water column volume available to dilute before reaching the 500 m horizontal distance from the discharge location (**Figure 5**) making the distance from the discharge to the seabed important.

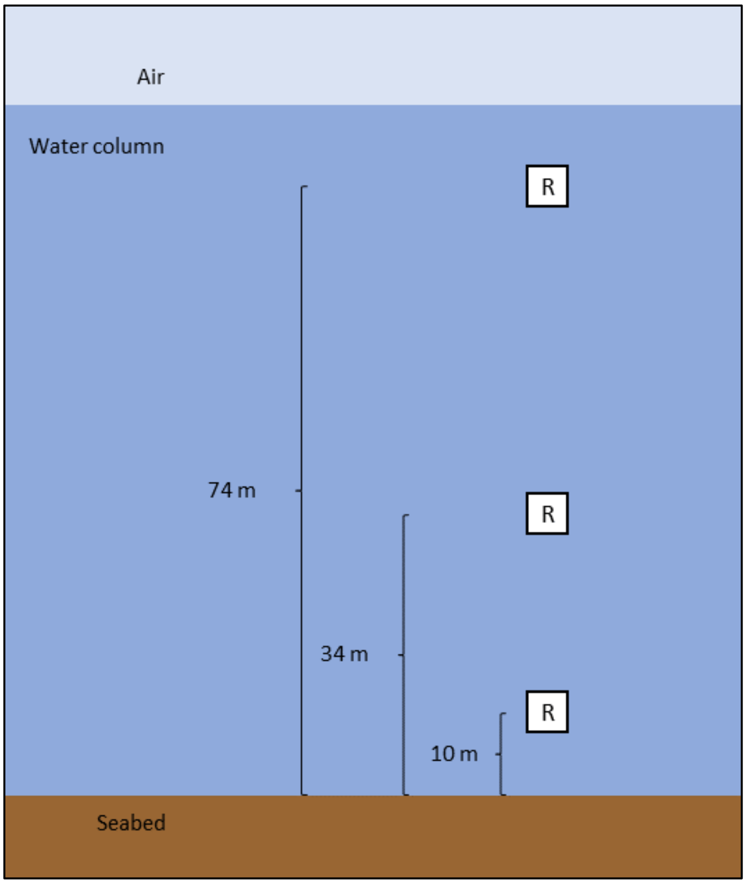

Figure 5: Schematic of CNS discharge locations (noted R) in relation to distance to seabed

An illustration of the availability of water column for dispersion is shown in Figure 6. Releases (denser than surrounding seawater) with greater water column below them have more capability to disperse than those with less water column beneath them and hence generate a higher DF. Conversely, if a release that was less dense than surrounding seawater was modelled it is likely that the DF value would be lower for the release closer to the sea surface and higher for the one closer to the seabed.

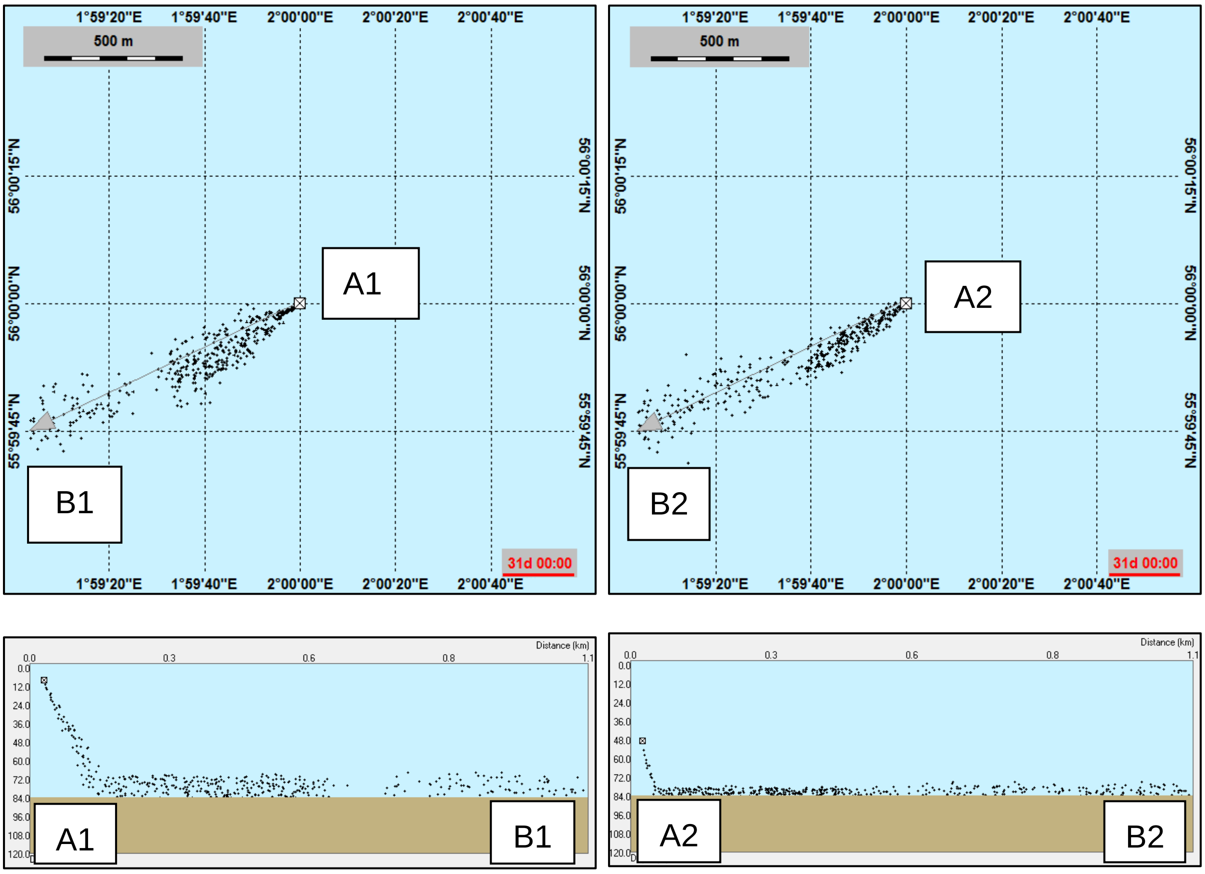

Figure 6: Comparison of discharges (75,000 m^3/yr) with different release depth (10 m (left) and 50 m (right)) and therefore water column below them

Due to the influence of proximity to the seabed (34 m or less in modelled scenarios here) on minimum DF it was decided that these data should be analysed separately. Average DFs of the complete and filtered dataset are provided (Table 4). Sample size (n) of each average and error (standard deviation) calculated for the dataset with values excluded is n = 4 and without values excluded is n = 6. DFs of near-seabed discharges (excluded values discussed above) are presented as averages and errors in Table 5.

Table 4: Average DFs for varying discharge rates

Discharge rate ($m^3\ yr^{-1}$)	Whole dataset		Exclusion of CNS 50 and 74 m discharges	
	Average minimum DF[1]	Average median DF[1]	Average minimum DF[2]	Median DF[2]
25,000	19,717 ± 6,546	4,459,085 ± 2,482,635	22,731 ± 4,479	5,322,728 ± 2,647,151
75,000	11,498± 5,106	1,429,858 ± 635,973	14,683 ± 746	1,694,004 ± 616,404
125,000	7,558± 3,479	811,128 ± 367,679	9,712 ± 908	935,265 ± 393,968

[1]n = 6 and [2]n = 4. Errors represent standard deviation.

Table 5: Average of near-seabed CNS discharge DFs only

Discharge rate ($m^3\ yr^{-1}$)	Average minimum DF[1]	Average median DF[1]
25,000	13,690 ± 6715	2,731,799 ± 919,027
75,000	5,128 ± 2637	901,565 ± 212,536
125,000	3,249 ± 1528	562,854 ± 159,335

[1]n = 2. Errors represent standard deviation.

Statistical Modelling

Models of minimum DFs as a function of discharge rate, depth and location did not vary significantly with either depth nor location (note exclusion of near seabed values, detailed modelling results are summarised in Appendix B). Therefore, depth and location were excluded from the final model (p-values > 0.05; significance is defined here as when p-values < 0.05) where only the coefficient for discharge rate and intercept were kept (Table 7 and Figure 27).

In models of median DF, only location was identified as a non-significant term (p-value > 0.05). Therefore, location was excluded from the final model (p-values > 0.05) where only the coefficients for discharge rate, depth and intercept were kept (Table 7 and Figure 28).

DF (both minimum and median) were log-transformed (log10(DF)) to improve the randomness of errors and normality (Figures 27 and 28 in Appendix B). However, the minimum DFs model suffers from skewed estimations at low and high values.

The models reported here can be used to estimate the minimum and median DFs using equations 1 and 2, respectively (Figure 7 and **Figure 8**):

$$DF_{\text{Minimum}} = 10^{4.440639-3.642509\times10^{-6}DR}; \quad \text{(Eq. 1)}$$

$$DF_{\text{Median}} = 10^{7.025743-7.504481\times10^{-6}DR-3.866531\times10^{-3}z}; \quad \text{(Eq. 2)}$$

Where DR is the discharge rate ($m^3\ yr^{-1}$) and the z is the discharge depth (m).

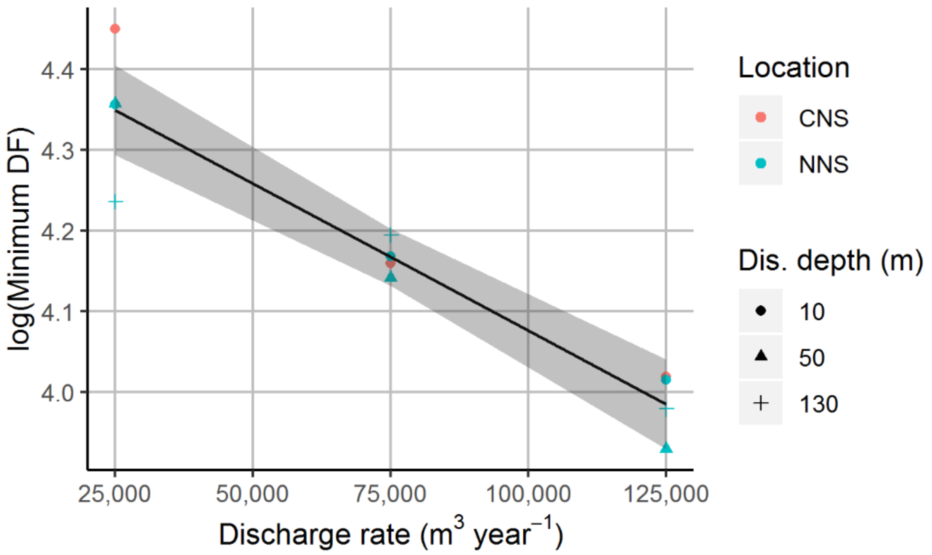

Figure 7: Minimum DFs (log-transformed) and model estimate (black line), grey bands represent 95% confidence intervals

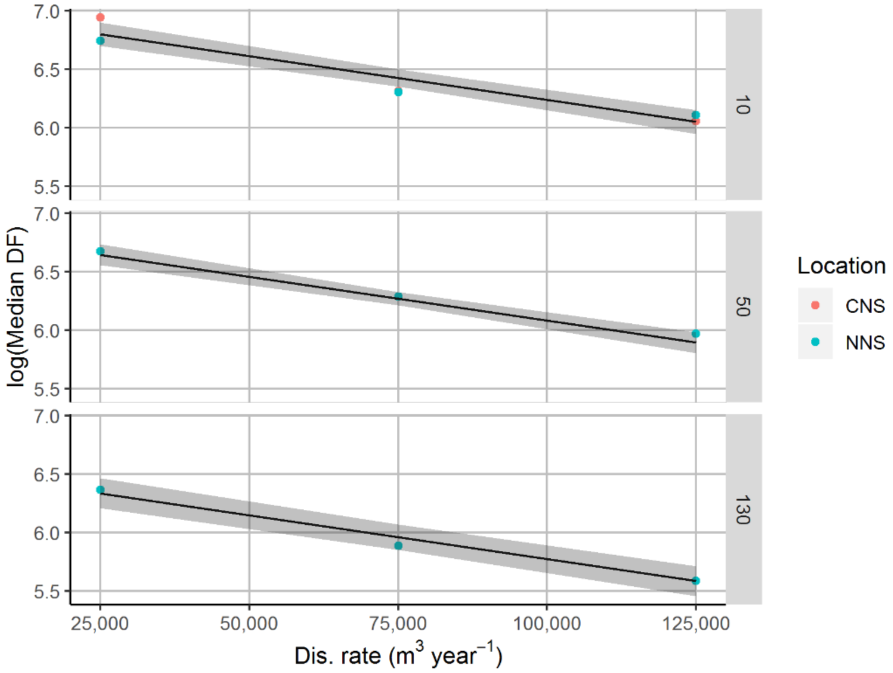

Figure 8: Median DFs (log-transformed) and model estimate (black line), grey bands represent 95% confidence intervals, plots are separated by discharge depth (top to bottom; 10, 50 and 130 m deep)

Proposed revised DF values

The simulations undertaken and reported here suggest that the key parameter driving DFs is the PW discharge rate. The discharge depth is only an important driver of DF when discharges take place near the seabed as evidenced in the CNS (84 m deep) for discharges at 50 and 74 m. The results of the modelling can be used to update the DF table found in the RBA guidelines. The derived minimum DFs have been used rather than derived median DFs as this ties in with the methodology used previously, with the deliberate intention that Tier 2 should be conservative (DECC, 2014). The use of minimum DFs is conservative as the equivalent maximum concentrations may only be present in the water column for a brief period of time in each simulation. A separate study (Genesis, 2019) has suggested that the use of median DFs may be more representative of actual dilution.

The following updates are proposed (Table 6):

- Update of definition of depth changed to “Water depth below discharge (m)” due to the influence of close proximity to the seabed as evidenced in near-seabed CNS discharges modelled here;
- Insertion of two additional columns to capture the lower discharge range;
- Change the previous range of < 100,000 m^3 yr^{-1} to cover 75,000 to 125,000 m^3 yr^{-1} to align with the modelling exercise undertaken here; and
- Use minimum DFs presented in Table 4 and Table 5 for each discharge range, rounded to the nearest thousand:
    - Statistical modelling of minimum DFs for discharges over 34 m from the seabed resulted in discharge depth not being a significant term and therefore the same values have been applied for categories of 50,000–125,000 and > 125,000 across water depths below discharge; and
    - Minimum DFs of near-seabed PW discharges modelled (Table 4) have been included in the first row (“< 50 m”) of Table 6 as these represent the limited availability of water column for the dispersion of dense PW discharges (PW modelled here was denser than surrounding seawater).

Table 6: Proposed updated DF table

Water depth below discharge (m)	Annual PW discharge volume (m^3 yr^{-1})					
	< 25,000	**25,000–75,000**	**75,000–125,000**	**125,000–1,000,000**	**1,000,000–8,000,000**	**> 8,000,000**
< 50	14,000	5,000	3,000	1,000	400	100
50–125	23,000	15,000	10,000	4,000	400	100
> 125	23,000	15,000	10,000	8,000	400	100

Note: updated cells are shaded grey and new proposed values of DFs shown in bold

Minimum DFs for discharges at 125,000 m^3 yr^{-1} tied in well with those of the previously supplied table for values between 100,000–1,000,000 m^3 yr^{-1} (~9,700 rounds to 10,000). This close tie-in suggests that using outputs from this modelling exercise to expand upon the existing DF table is valid.

An alternative approach would be to utilise the linear model of minimum DFs reported in Table 7, specifically those of minimum DF as these are the ones that best tie-in with the existing RBA DF. Note that this equation (Eq. 1) would only be applicable to discharges < 125,000 m^3 yr^{-1} and over ~40 m above the seabed. A worked example is provided below for an installation with a discharge rate (DR) equal to 25,000 m^3 yr^{-1}:

$$\mathrm{DF}_{\mathrm{Minimum}} = 10^{4.440639-3.642509\times10^{-6}\times25{,}000} = 22{,}365$$

Conclusions and Recommendations

A total of 18 PW discharge scenarios were modelled to evaluate the effects of discharge rate, discharge depth and location on DFs.

Inspection of the results suggested that discharges close to the seabed led to markedly different DFs than those of shallower discharges. Therefore, this was considered an external factor and sufficient to warrant separate analysis of DFs from simulations where this effect was observed (six in total). Correlation between discharge rate and DFs was significant and correlation between discharge depth and DFs was significant only for median DFs, not minimum DFs. While location was not a significant parameter for either DF type, it is important to note that only two locations were sampled so this may be a generalisation. To be certain location is not important, multiple discharge locations would need to be modelled.

There was good agreement between minimum DFs modelled here and those used in the previous RBA guidelines for discharges around 100,000 m^3 yr^{-1} (Table 1, DECC, 2014) as shown in Table 6.

An interesting finding of this study was that the effect of seabed proximity was only apparent for a few modelled scenarios, suggesting that there may be a critical distance from the seabed (for each discharge rate) from which the effect of the seabed becomes important. In addition, this may only be relevant for dense discharges such as those modelled here. If discharges have a lower density than seawater then DF is hypothesised to be more dependent on the water column available above the discharge rather than that beneath it (as seen in these simulations) since the PW discharge will tend to rise. This phenomenon warrants further investigation in order to understand the drivers of PW discharge dispersion at sea.

It is important to note that the minimum DFs derived here are conservative as they are based on maximum concentrations, which only occur during brief periods of time within each simulation. An alternative approach for Tier 2 could be to consider median DF values (less conservative) which were found to be more representative of real dilution events (Genesis, 2019). However, the purpose of Tier 2 is to ensure that the risk associated with a PW discharge is not underestimated, and therefore is designed to be conservative. Further analysis of a PW discharge at Tier 3 analysis would allow installations to exit at Tier 3, if the risk associated with the PW discharge is shown to be adequately controlled. The purpose of this study was also to focus on installations with discharge of around 100,000 m3 yr-1 or less and therefore modelling of the higher discharge rates was not undertaken, meaning the DF for >125,000 m3 yr-1 would remain unchanged.

References

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Genesis (2019). Modelling of NORM Discharges in the UKCS. J74456L-A-TN-00001/D2.

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Appendix A- Modelling outputs

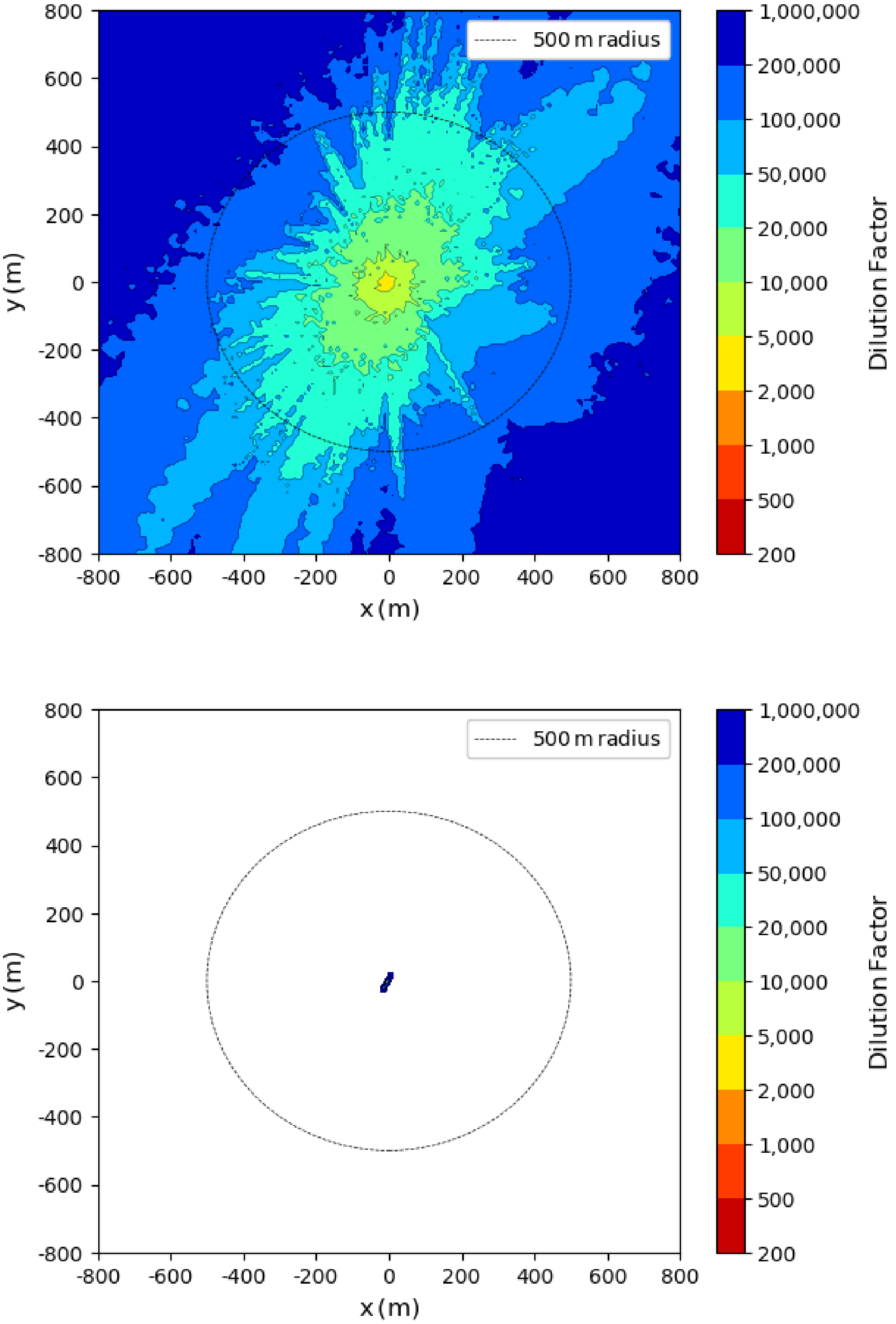

Figure 9: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 10 m deep and a discharge rate of 25,000 m^3 yr^{-1}

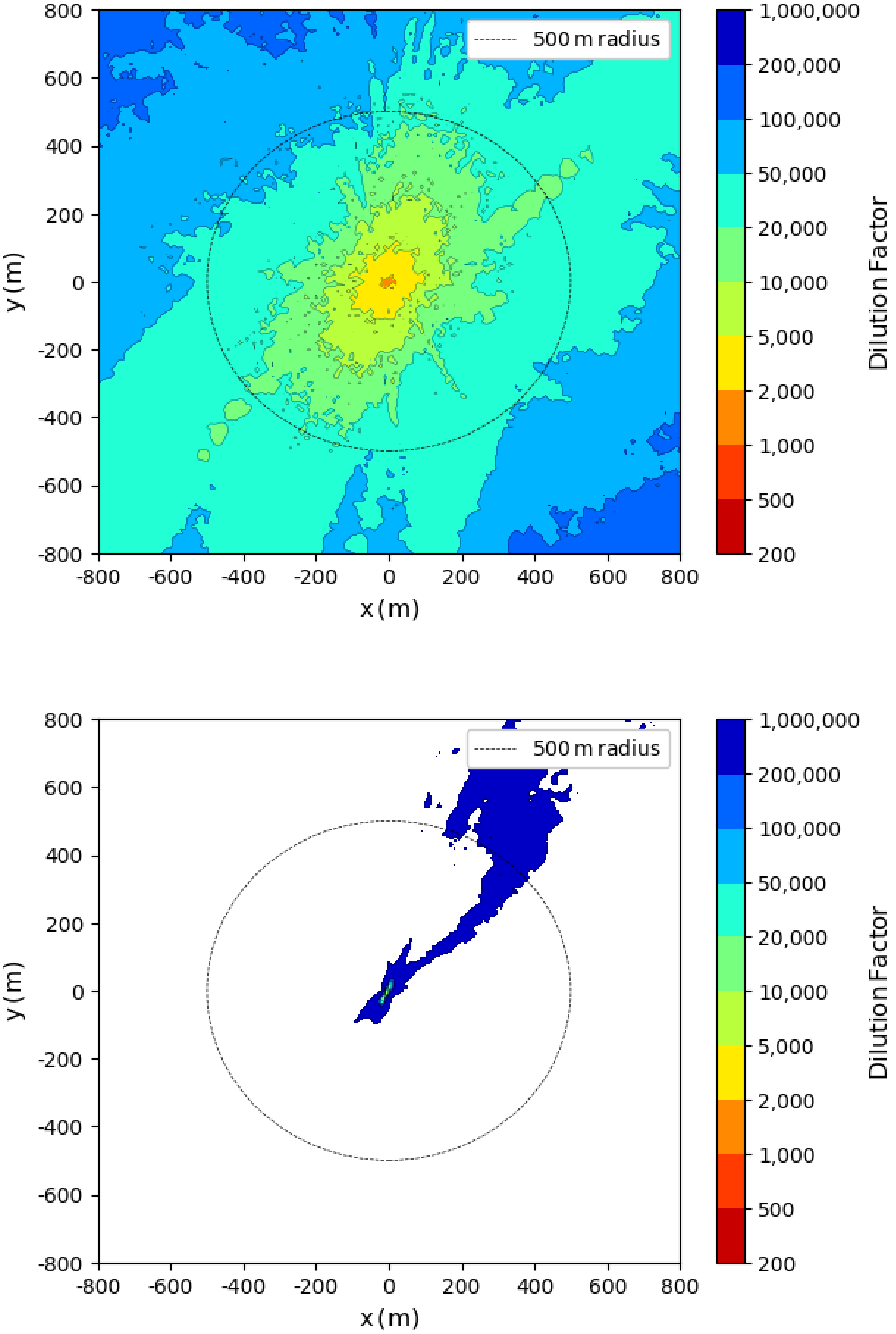

Figure 10: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 10 m deep and a discharge rate of 75,000 m^3 yr^{-1}

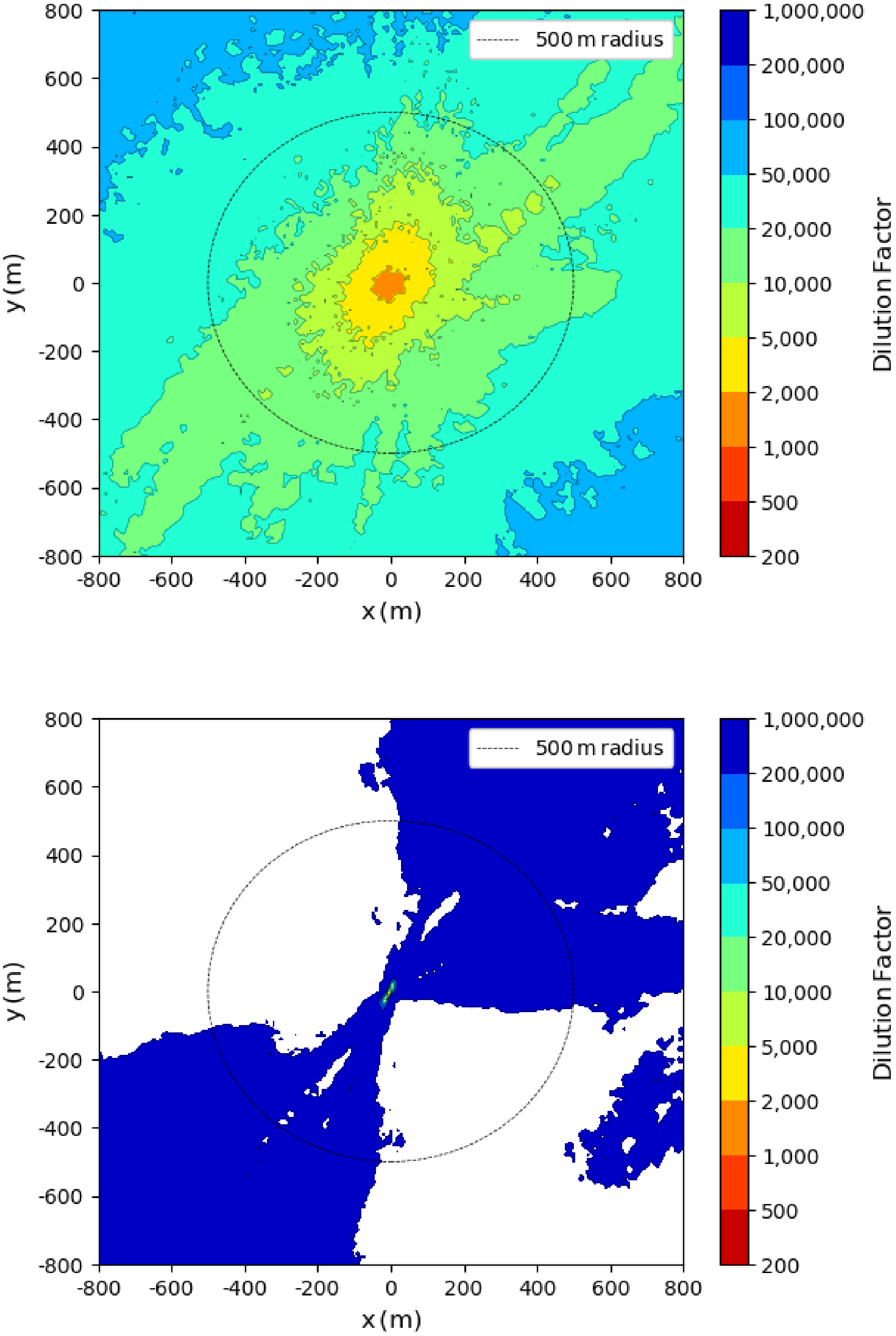

Figure 11: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 10 m deep and a discharge rate of 125,000 m^3 yr^{-1}

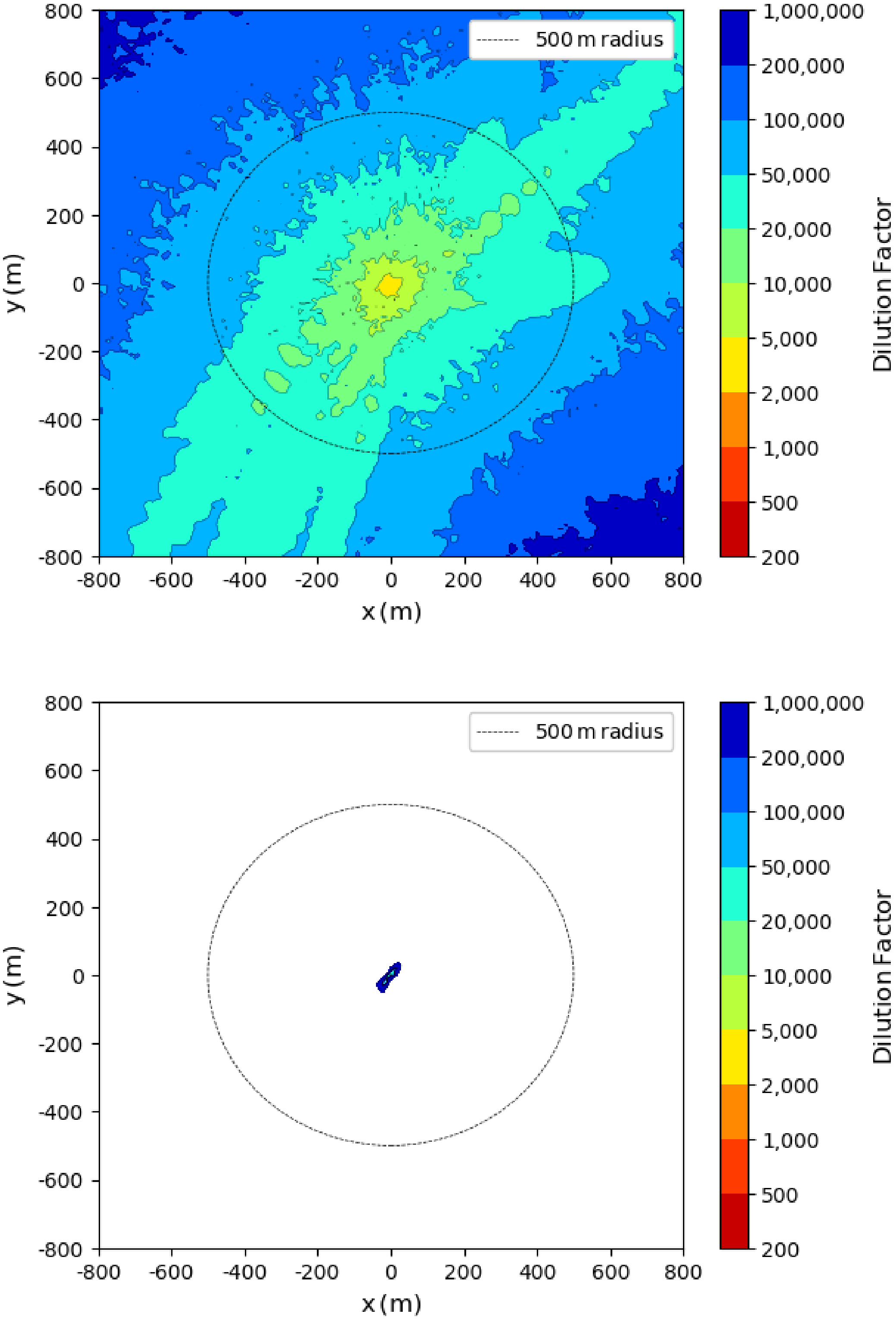

Figure 12: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 50 m deep and a discharge rate of 25,000 m^3 yr^{-1}

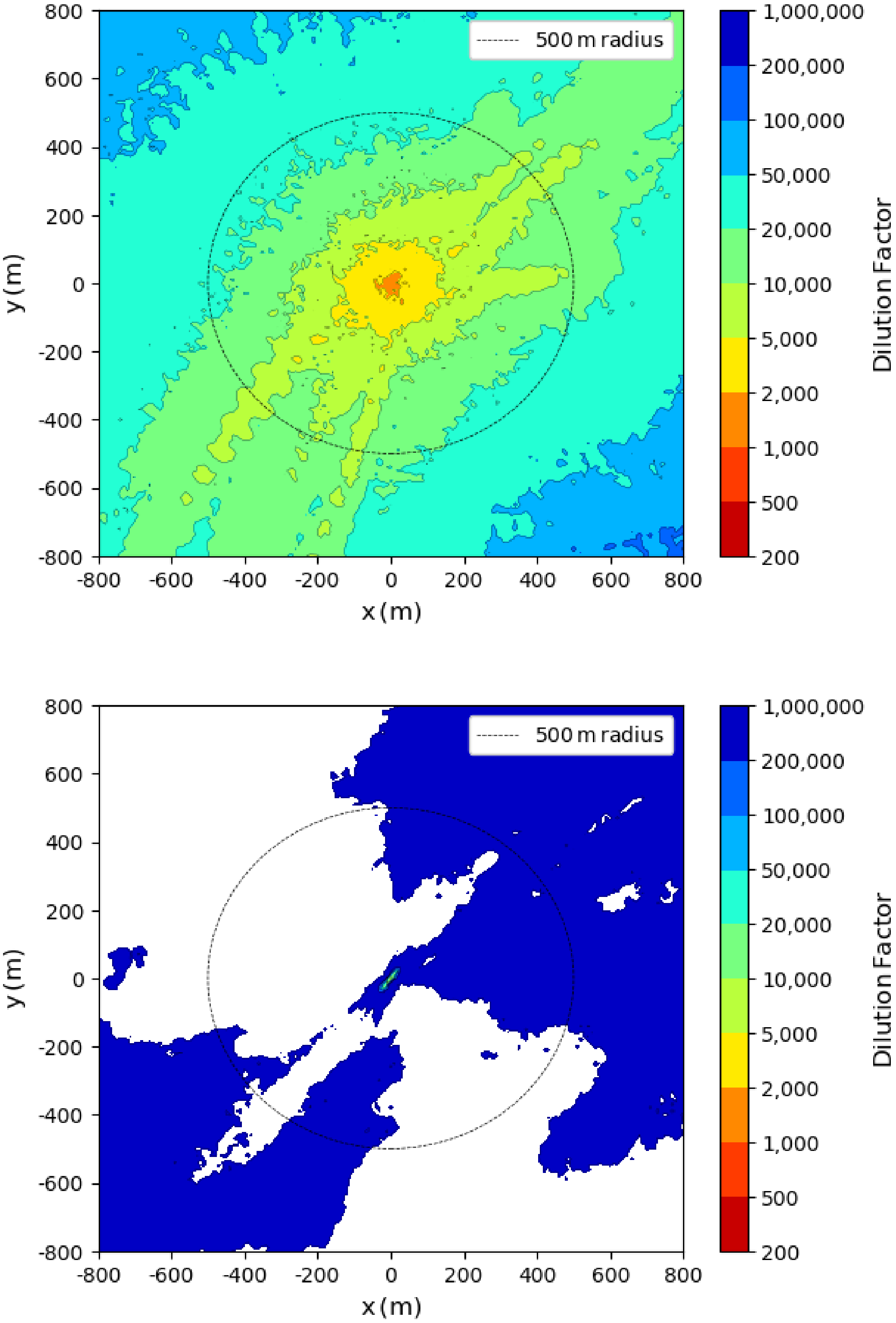

Figure 13: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 50 m deep and a discharge rate of 75,000 m^3 yr^{-1}

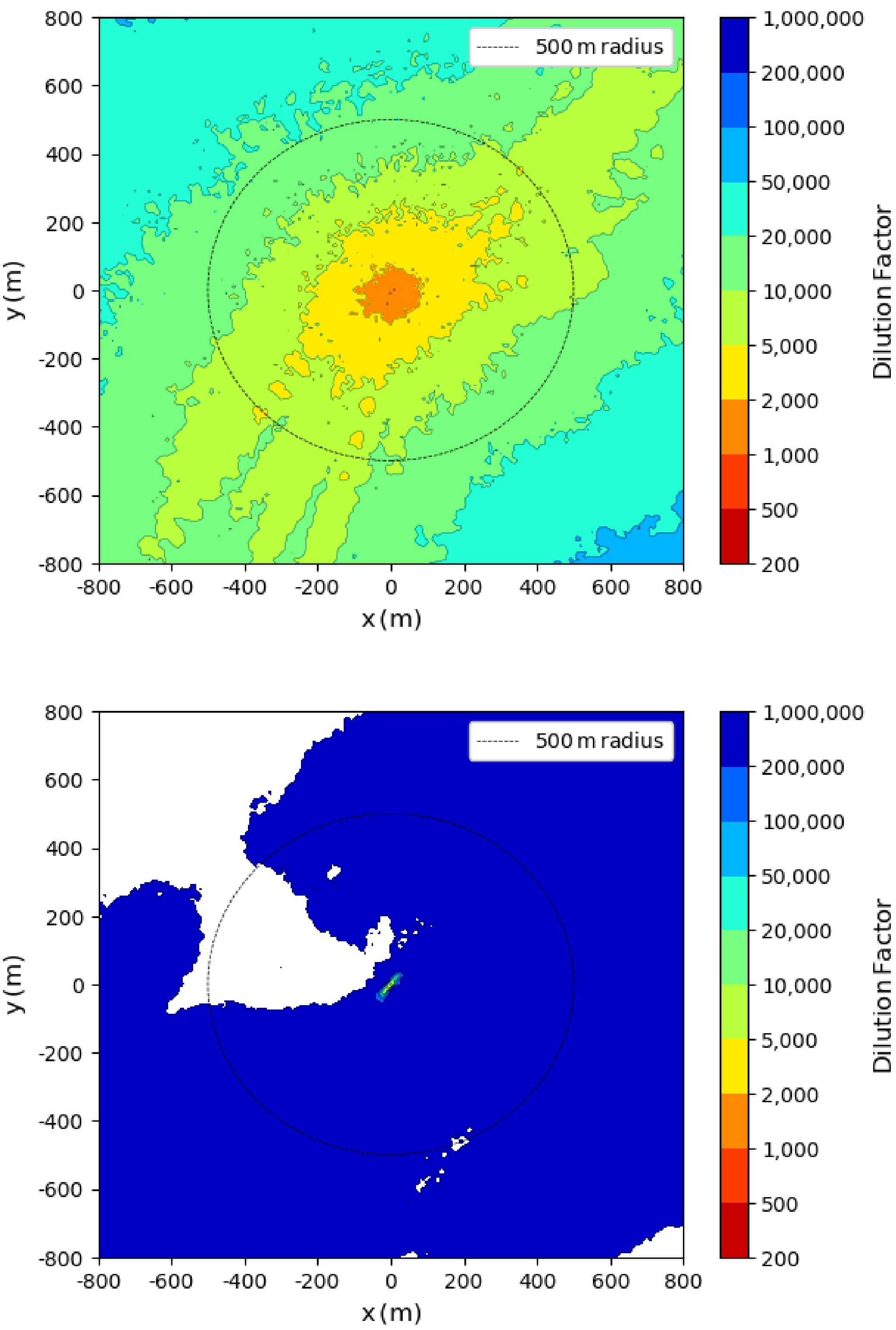

Figure 14: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 50 m deep and a discharge rate of 125,000 m³ yr⁻¹

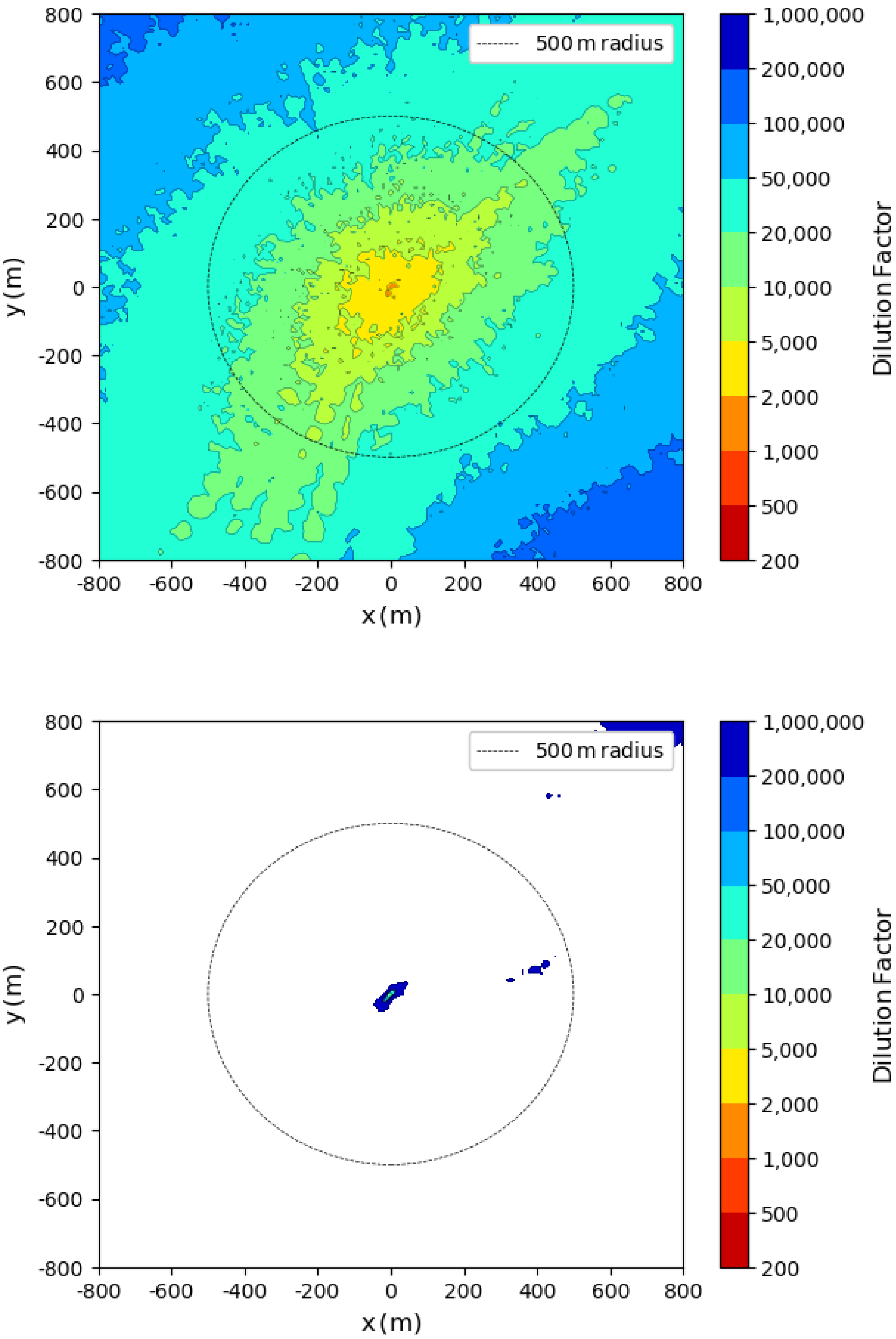

Figure 15: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 74 m deep and a discharge rate of 25,000 m^3 yr^{-1}

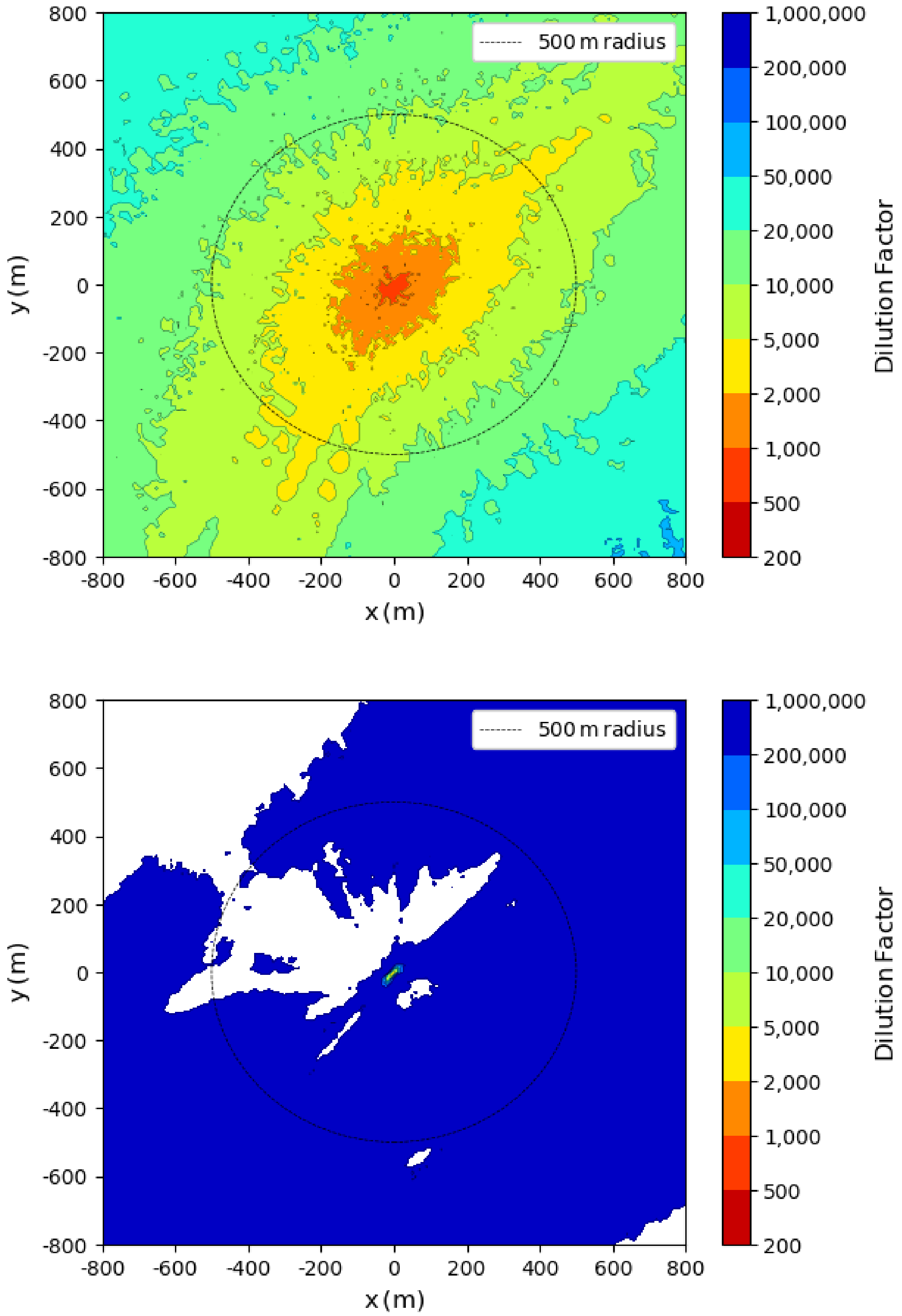

Figure 16: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 74 m deep and a discharge rate of 75,000 m^3 yr^{-1}

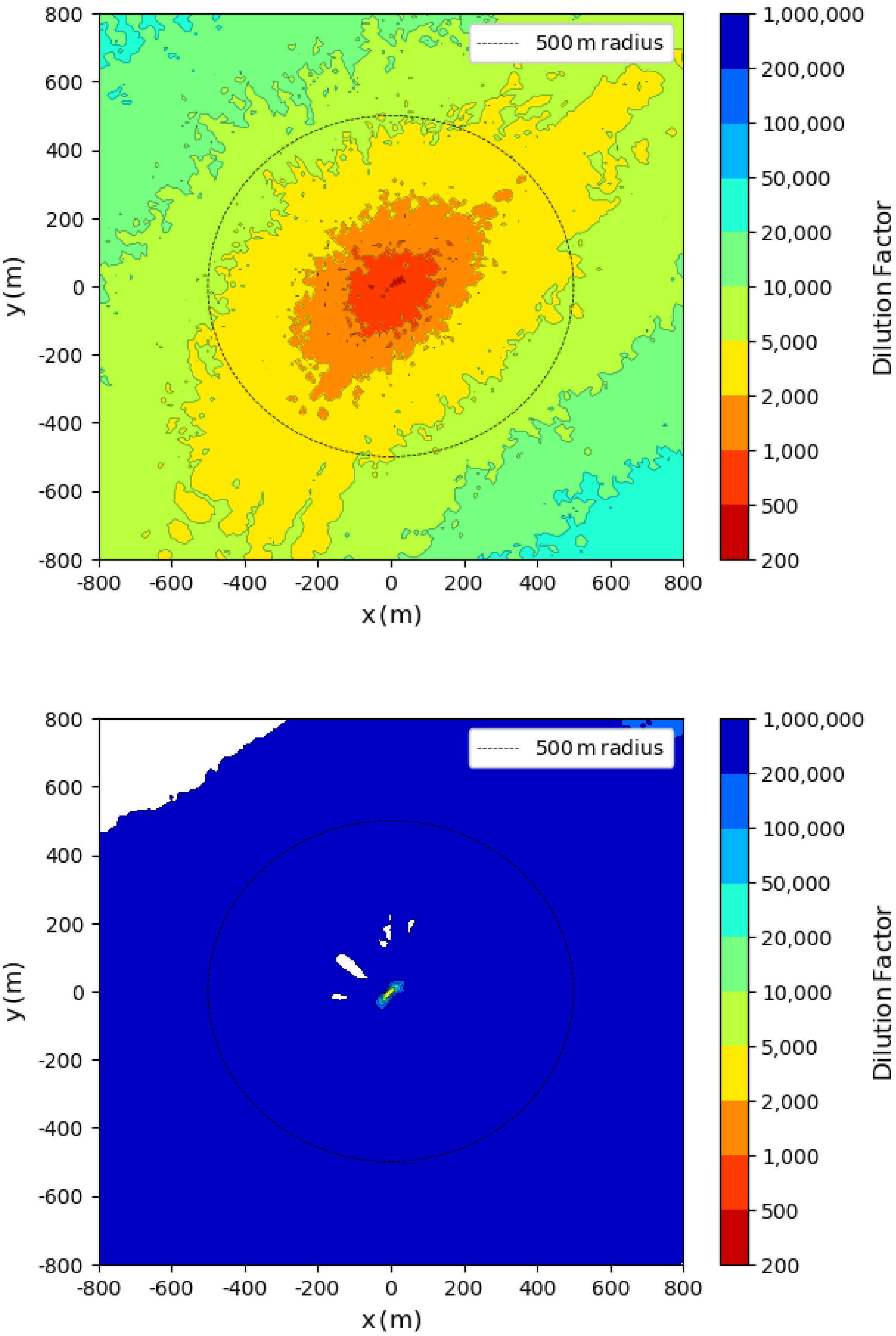

Figure 17: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 74 m deep and a discharge rate of 125,000 m^3 yr^{-1}

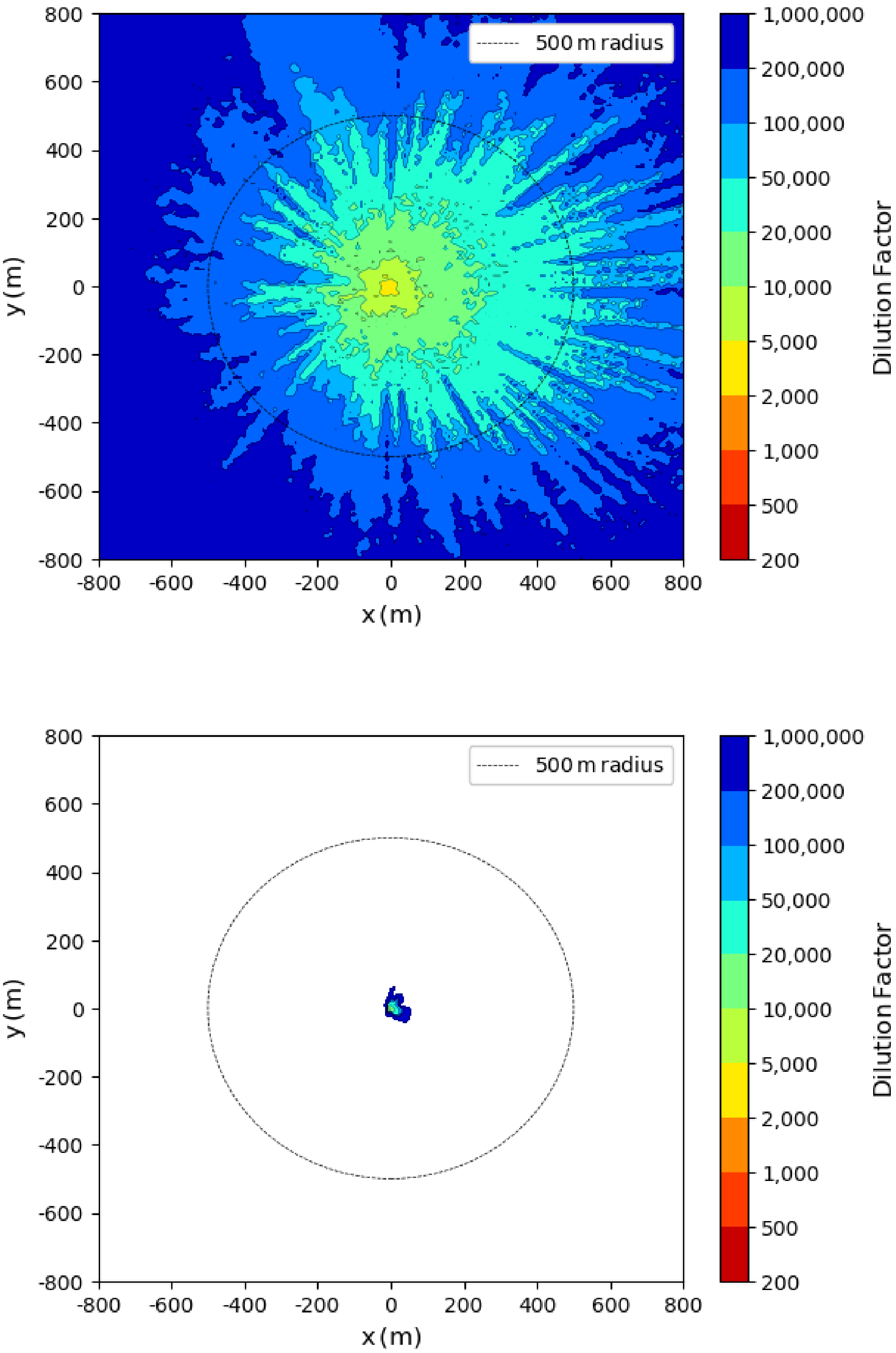

Figure 18: Minimum (top) and median (bottom) gridded DF for the simulation in the Northern North Sea at 10 m deep and a discharge rate of 25,000 m^3 yr^{-1}

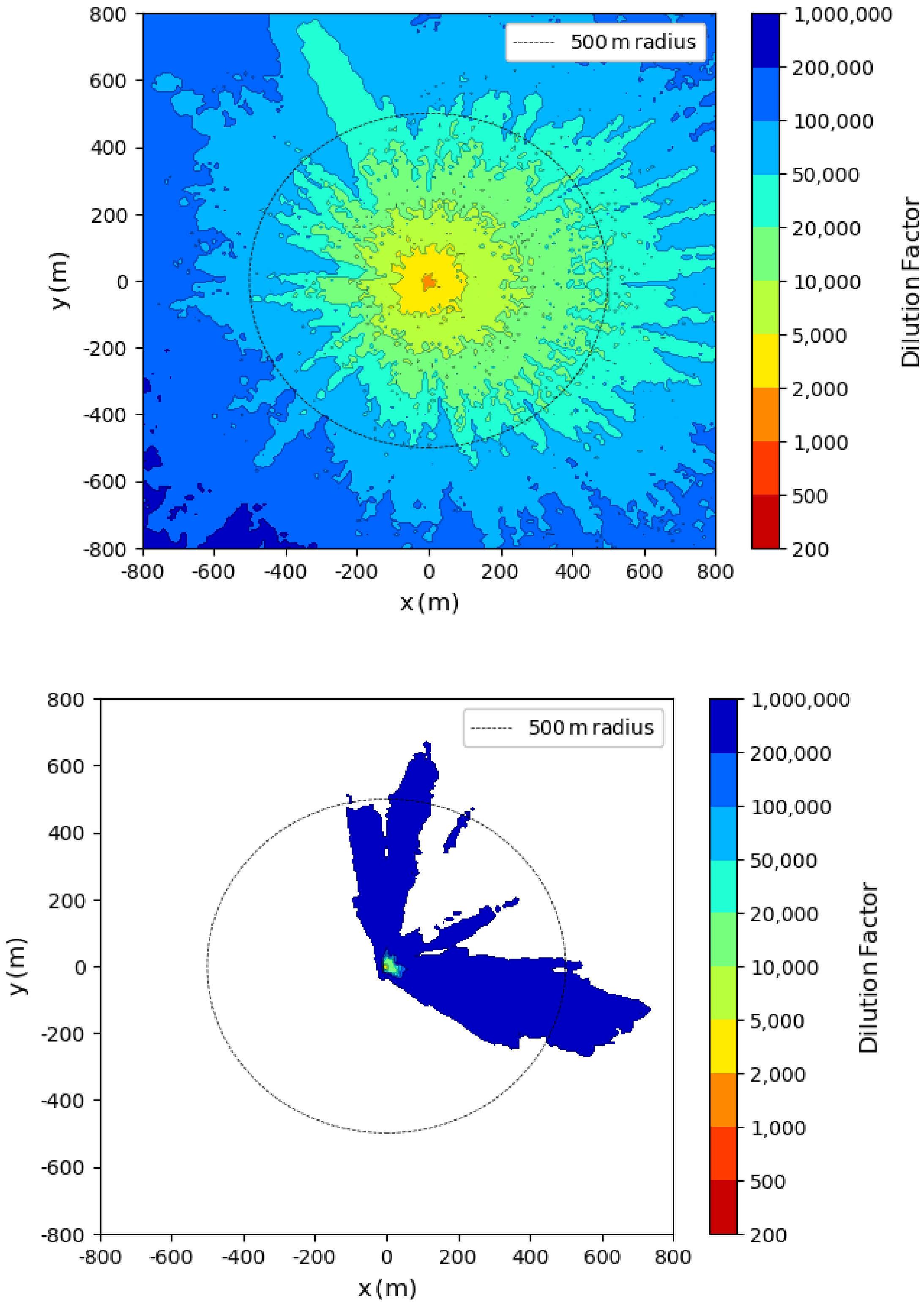

Figure 19: Minimum (top) and median (bottom) gridded DF for the simulation in the Northern North Sea at 10 m deep and a discharge rate of 75,000 $m^3\ yr^{-1}$

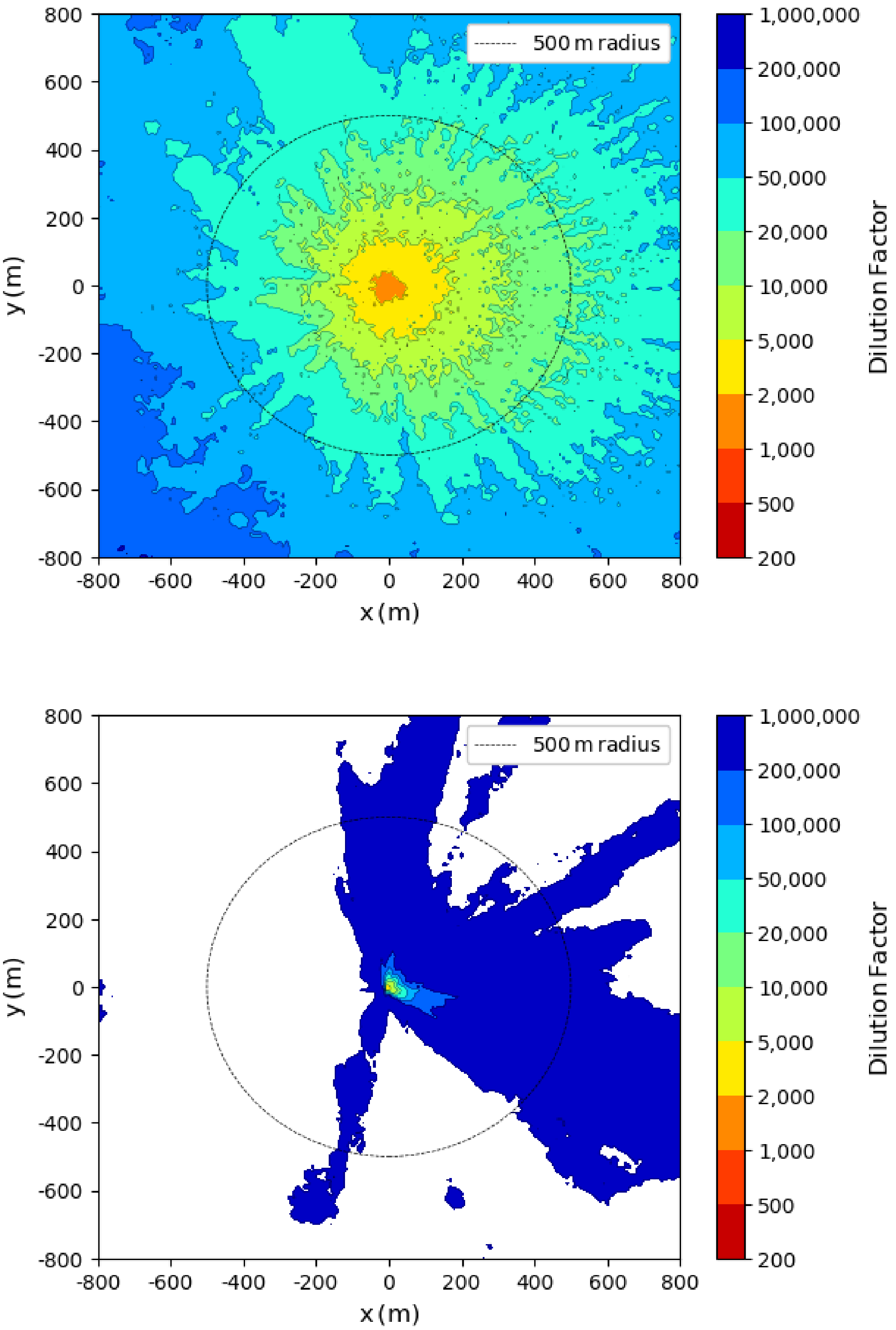

Figure 20: Minimum (top) and median (bottom) gridded DF for the simulation in the Northern North Sea at 10 m deep and a discharge rate of 125,000 m^3 yr^{-1}

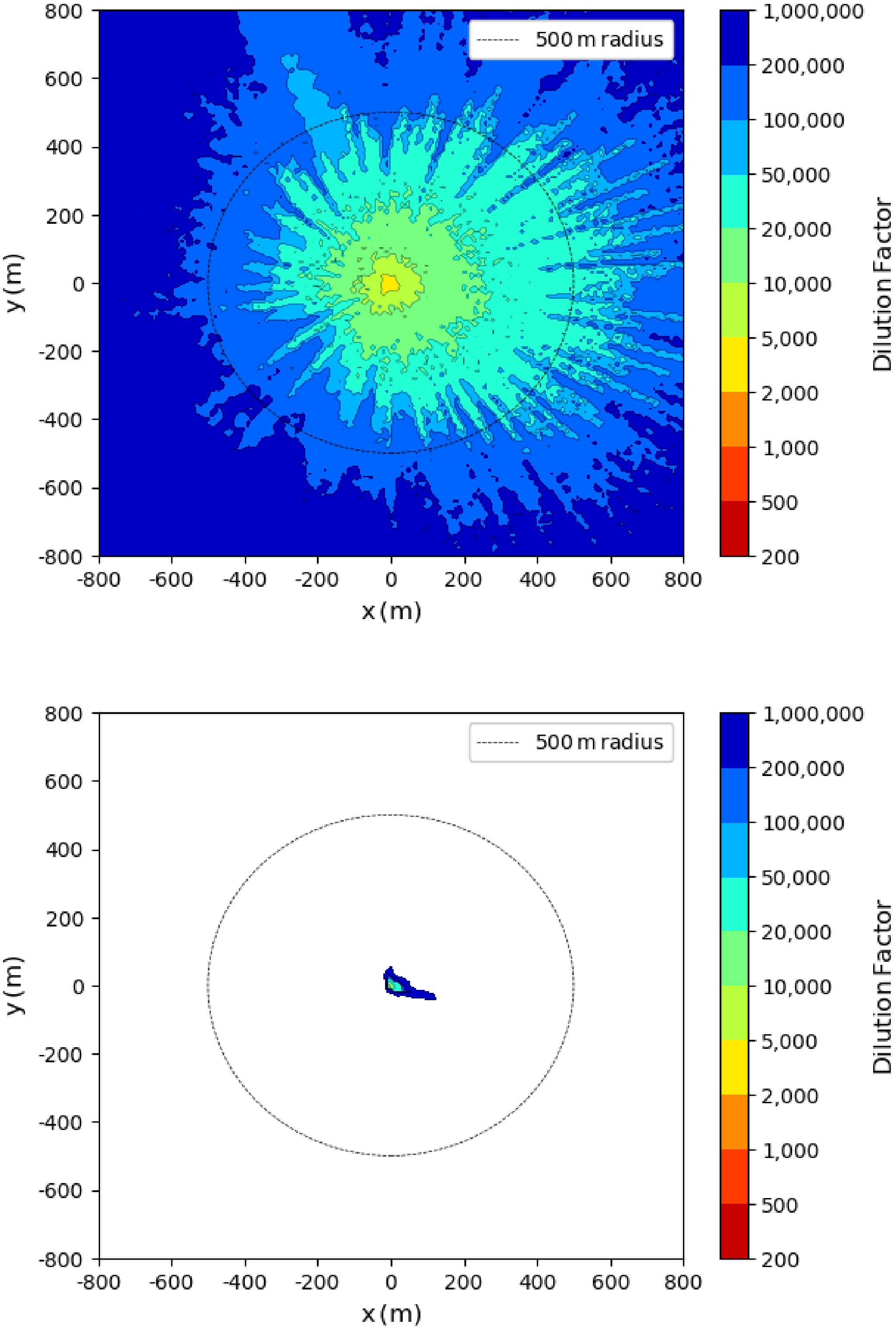

Figure 21: Minimum (top) and median (bottom) gridded DF for the simulation in the Northern North Sea at 50 m deep and a discharge rate of 25,000 m^3 yr^{-1}

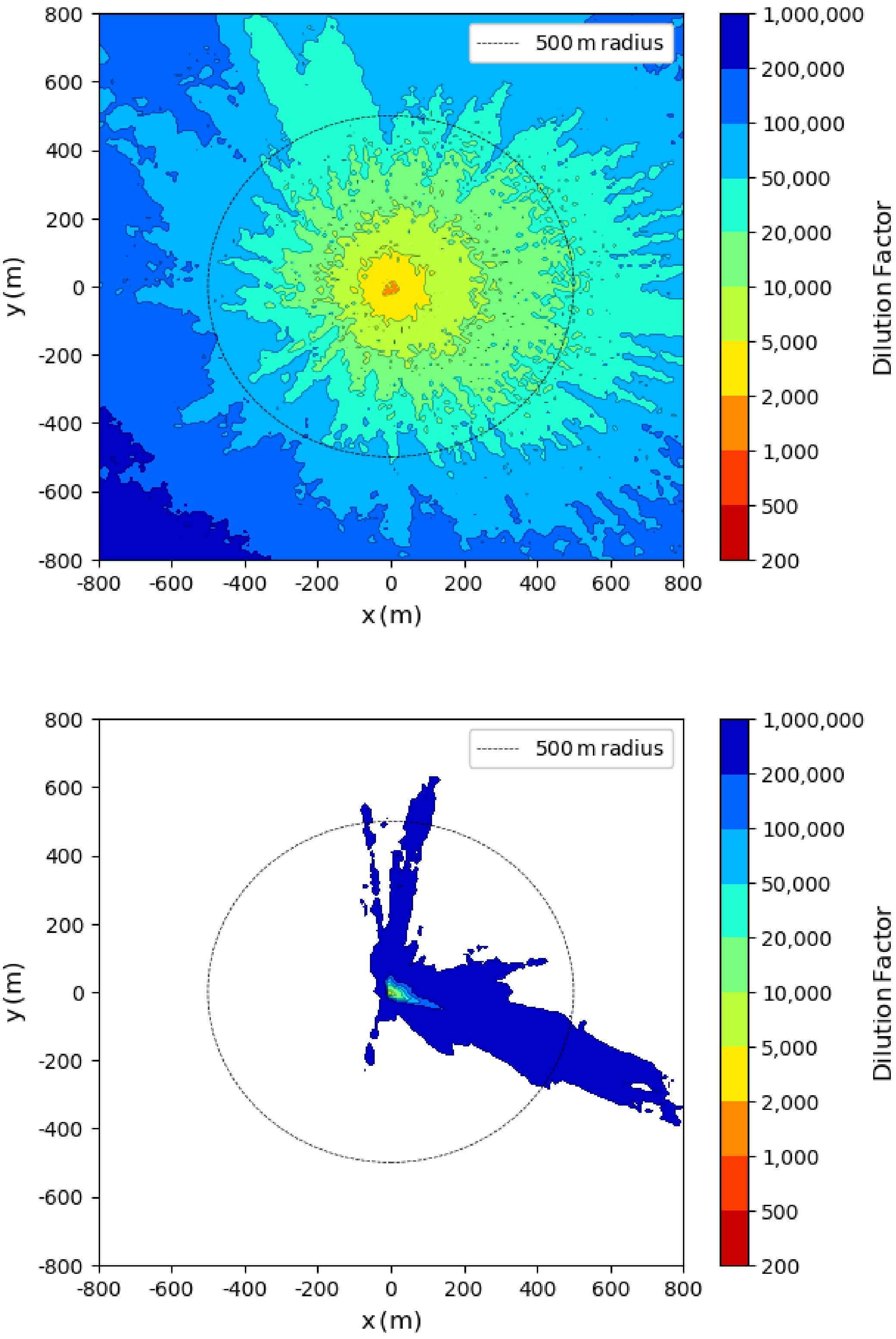

Figure 22: Minimum (top) and median (bottom) gridded DF for the simulation in the Northern North Sea at 50 m deep and a discharge rate of 75,000 m^3 yr^{-1}

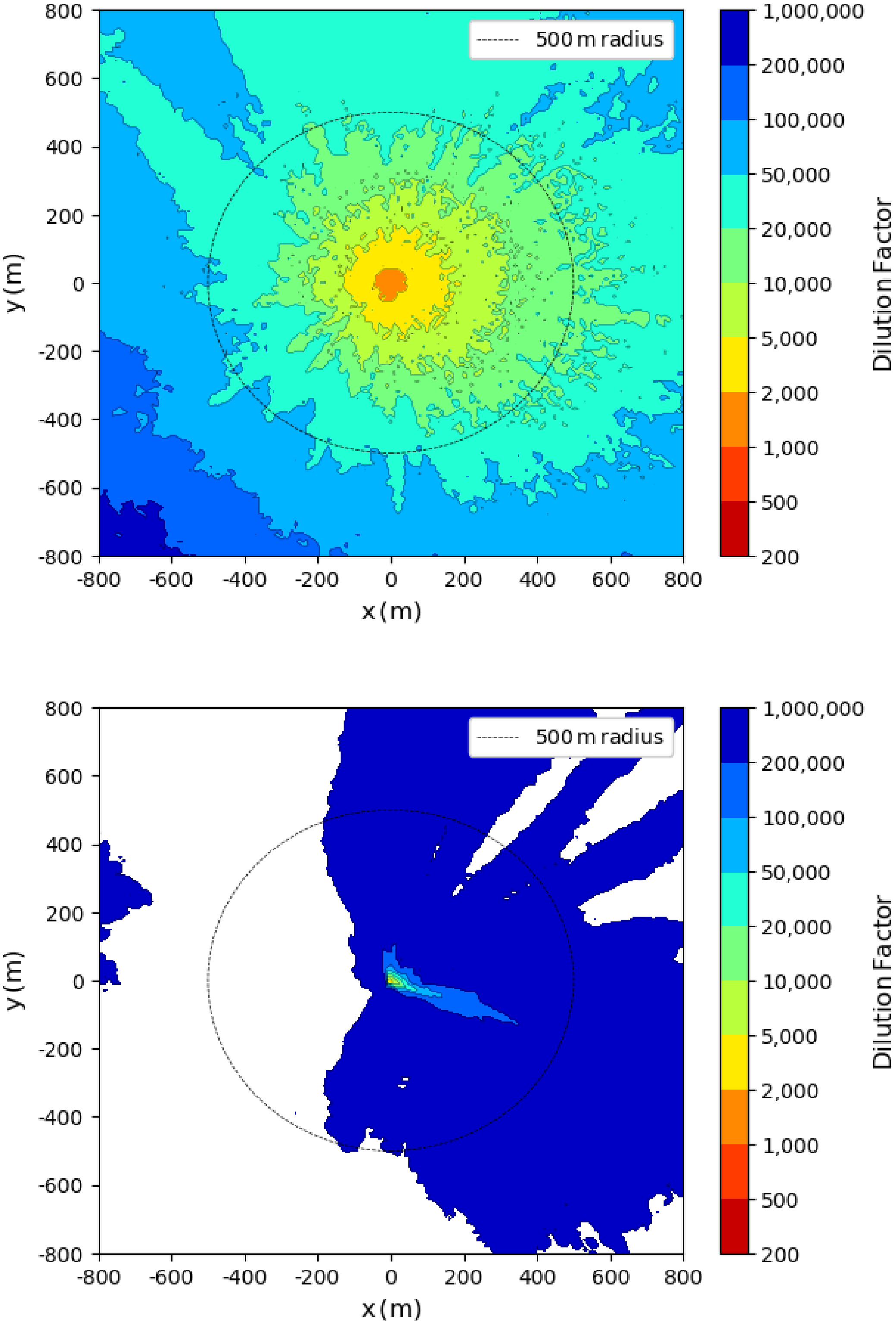

Figure 23: Minimum (top) and median (bottom) gridded DF for the simulation in the Northern North Sea at 50 m deep and a discharge rate of 125,000 m^3 yr^{-1}

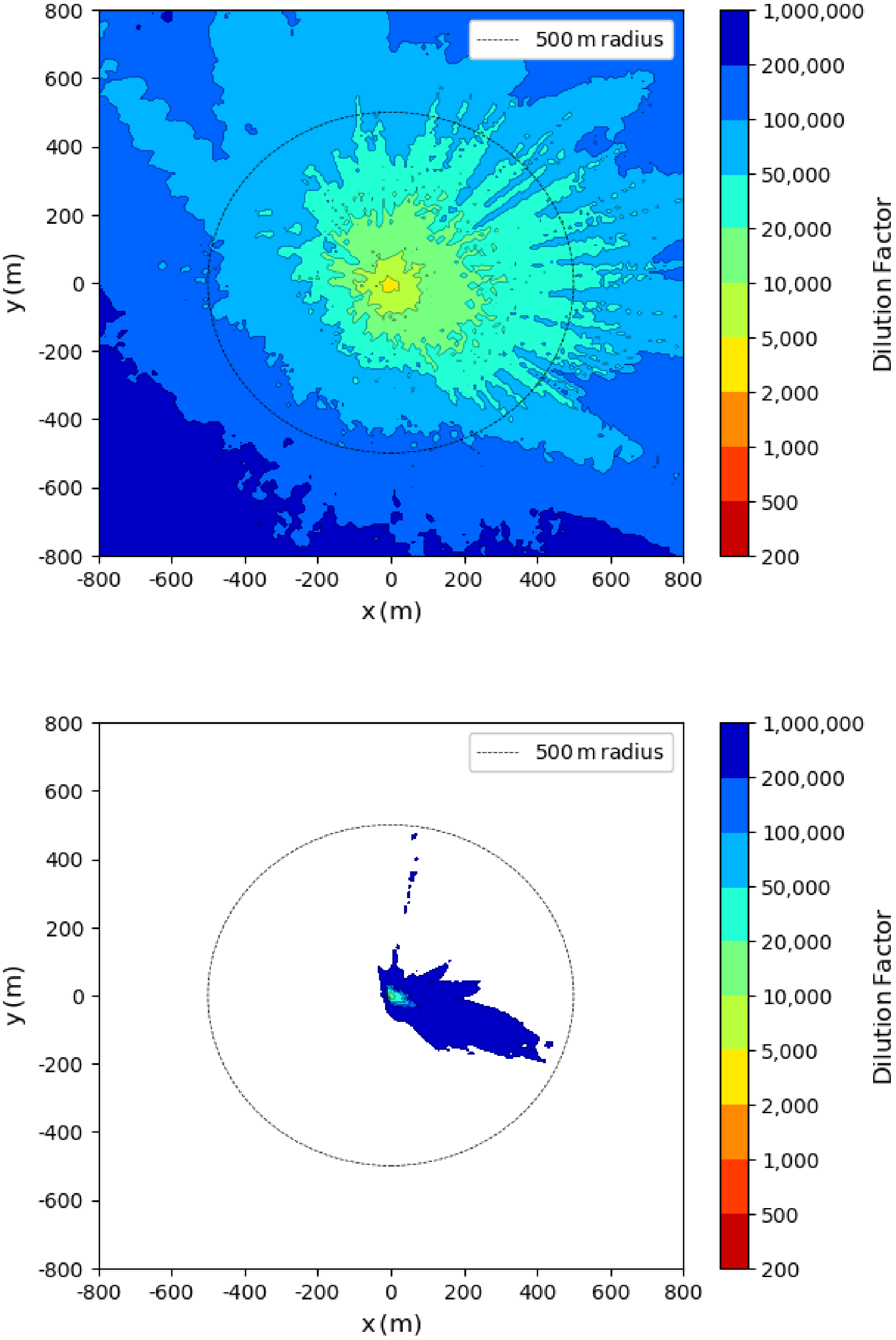

Figure 24: Minimum (top) and median (bottom) gridded DF for the simulation in the Northern North Sea at 130 m deep and a discharge rate of 25,000 m^3 yr^{-1}

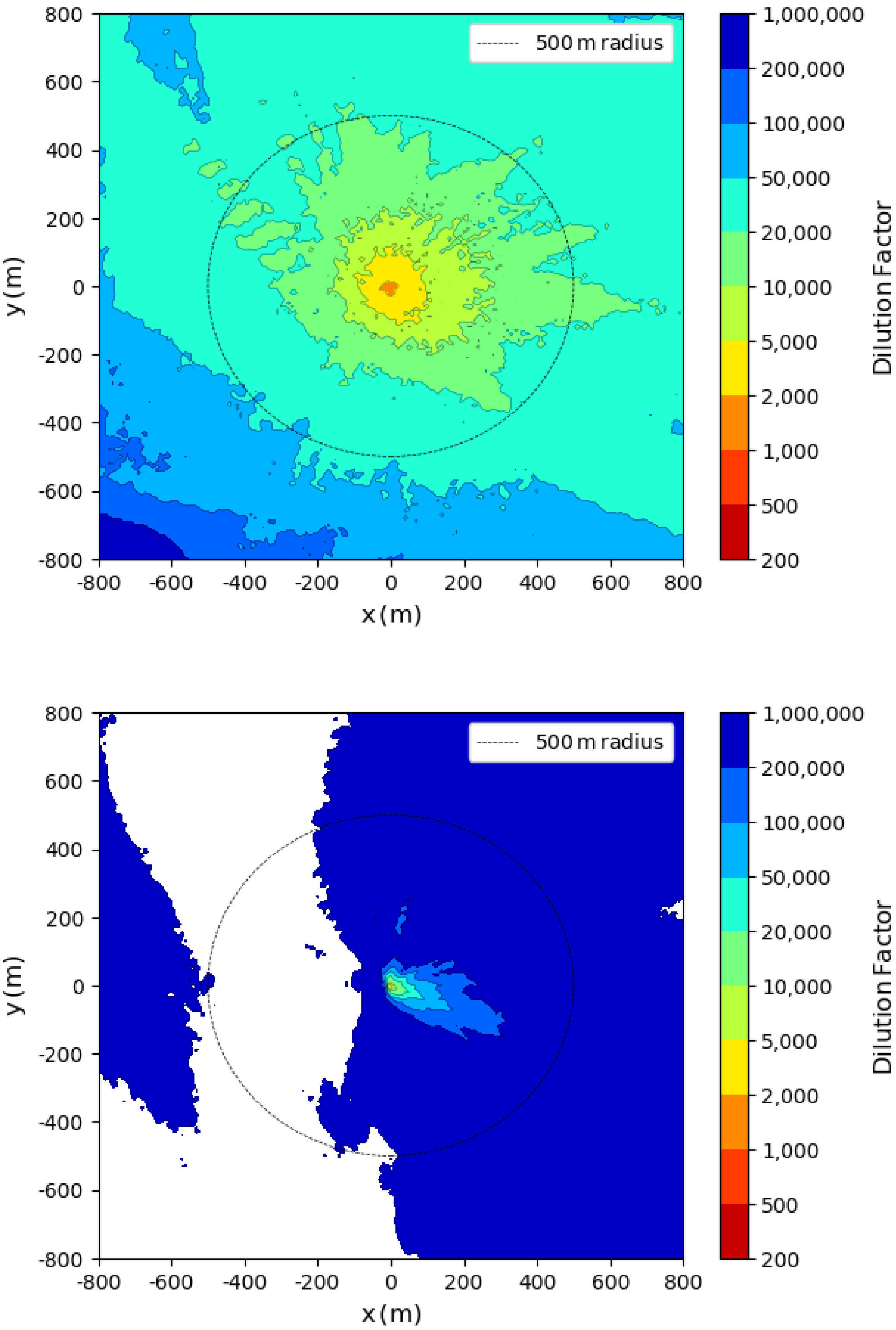

Figure 25: Minimum (top) and median (bottom) gridded DF for the simulation in the Northern North Sea at 130 m deep and a discharge rate of 75,000 m^3 yr^{-1}

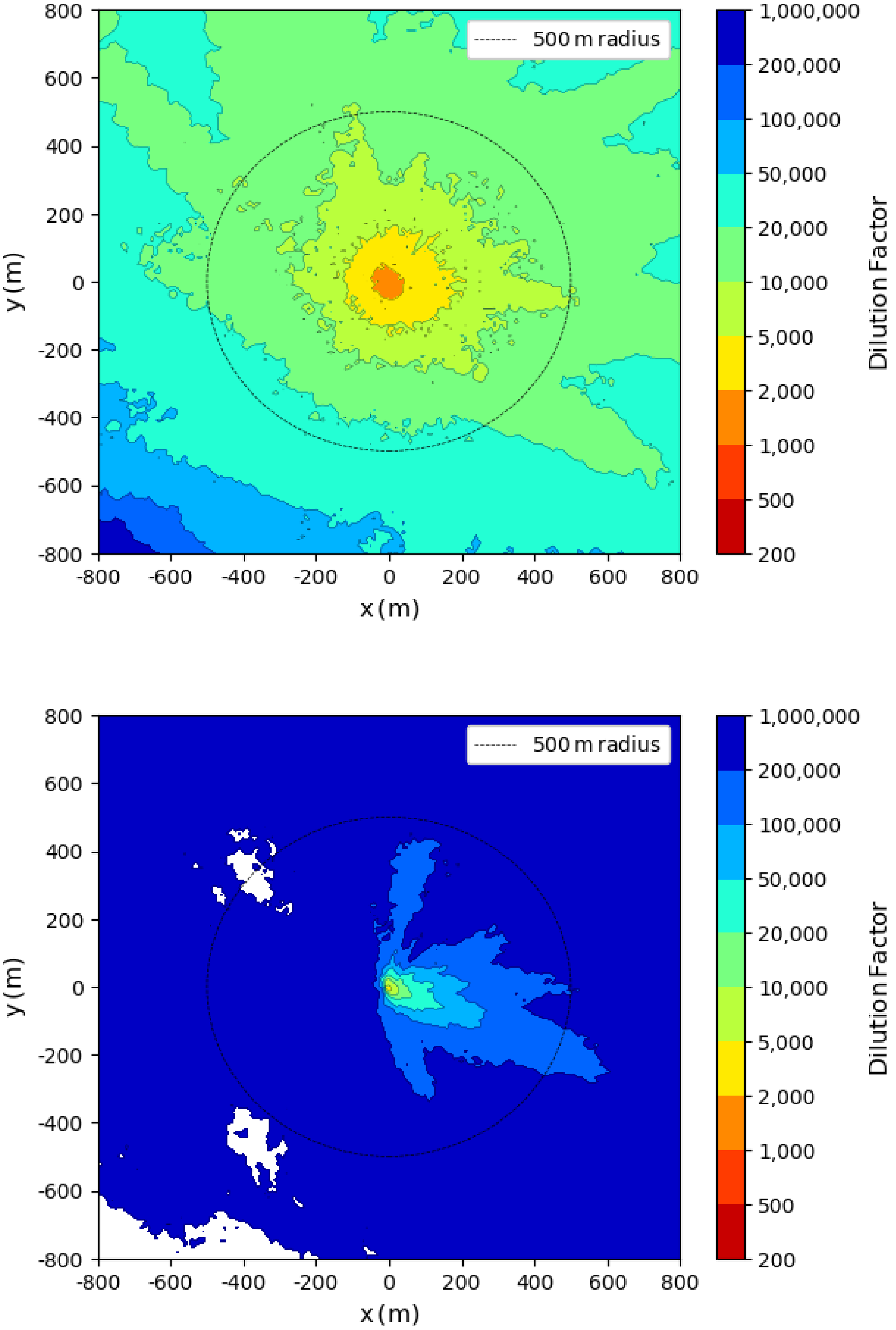

Figure 26: Minimum (top) and median (bottom) gridded DF for the simulation in the Central North Sea at 130 m deep and a discharge rate of 125,000 m^3 yr^{-1}

Appendix B – Statistical analysis

Table 7: Model summary of minimum and median DFs

DF	Coefficient	Estimate[1]	Standard error[2]	t-value[3]	p-value[4]
Log_{10}(Minimum DF)	Intercept[4]	4.440639	3.294073×10^{-2}	134.806942	$< 2 \times 10^{-16}$
	Discharge rate ($m^3\ yr^{-1}$)	-3.642509×10^{-6}	3.857624×10^{-7}	-9.442364	2.68×10^{-6}
Log_{10}(Median DF)	Intercept[4]	7. 025743	5.792369×10^{-2}	121.293089	8.94×10^{-16}
	Discharge rate ($m^3\ yr^{-1}$)	-7.504481×10^{-6}	6.096292×10^{-7}	-12.309911	6.19×10^{-7}
	Discharge depth (m)	-3.866531×10^{-3}	5.080243×10^{-4}	-7.610917	3.29×10^{-5}

[1] Estimates refer to the values by which each coefficient needs to be multiplied in each equation (equations 1 and 2).

[2] The standard errors report the residual standard error (positive square root of the mean square error) divided by the square root of the sum of the square of each variable.

[3] T-values report the estimate divided by the standard error.

[4] P-values report the probability of observing any value equal or greater than the t-value. A frequently used cut-off point is 0.05 and was used here.

[5] The intercept refers to the value of DF in the minimum or median DF models for which the discharge rate or the discharge rate and depth, respectively, are equal to zero.

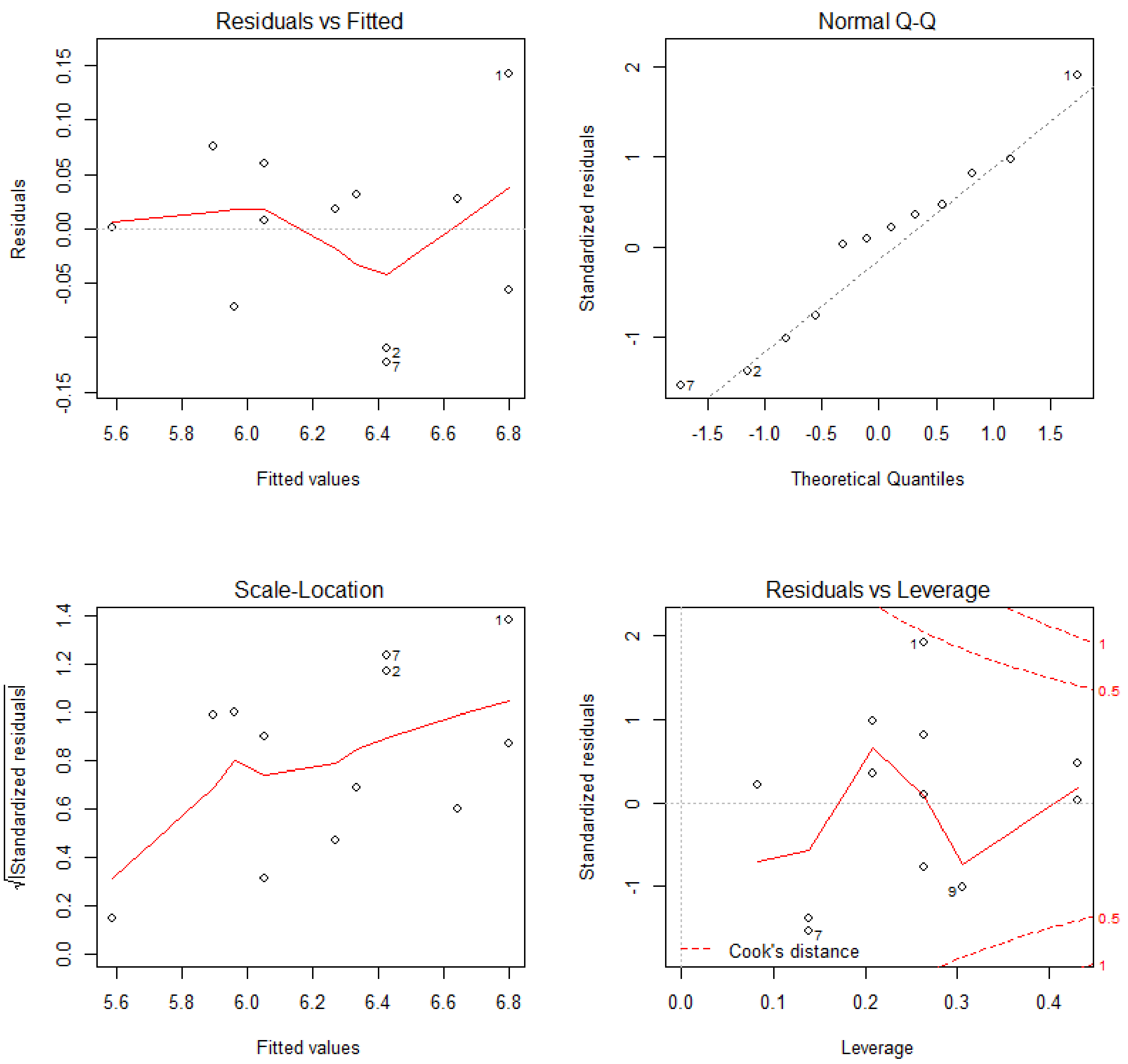
Residuals vs Fitted
Residuals
-0.15
-0.05
0.00
0.05
0.10
0.15
Fitted values
5.6
5.8
6.0
6.2
6.4
6.6
6.8
1
2
7
Normal Q-Q
Standardized residuals
-1
0
1
2
Theoretical Quantiles
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
1
2
7
Scale-Location
√|Standardized residuals|
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Fitted values
5.6
5.8
6.0
6.2
6.4
6.6
6.8
1
7
2
Residuals vs Leverage
Standardized residuals
-1
0
1
2
Leverage
0.0
0.1
0.2
0.3
0.4
1
9
7
Cook's distance
1
0.5
0.5
1

Figure 27: Median DF model diagnostics

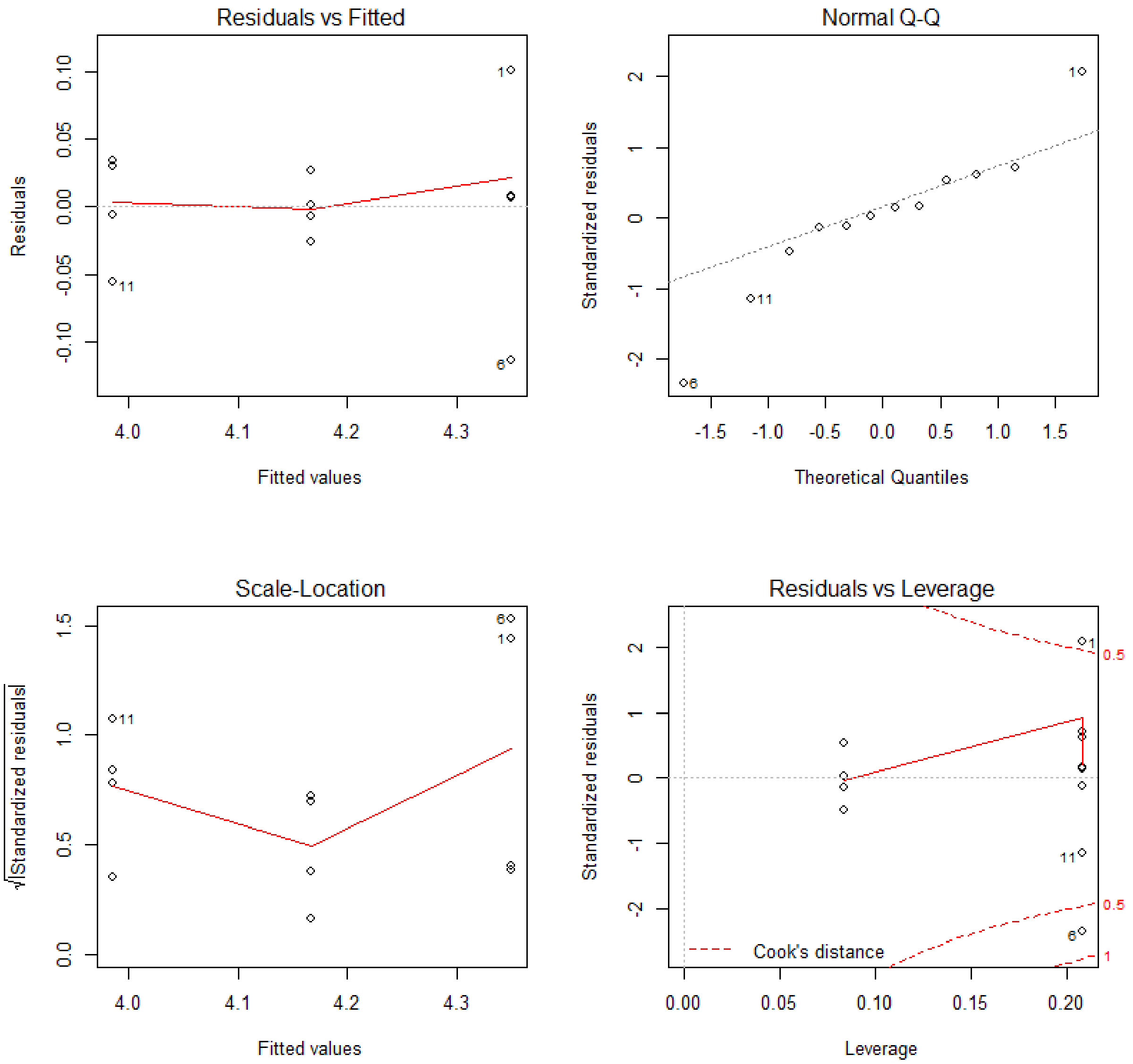

Figure 28: Minimum DF model diagnostics

Appendix C – Impact of new dilution factors on screening of low discharges

As noted at the start of this report, following the RBA implementation cycle and data gathered, BEIS had concerns that the existing DFs were too conservative, resulting in a number of installations having a PEC:PNEC ratio > 1 at Tier 2 even though subsequent modelling at Tier 3 showed them as having a low environmental risk. These concerns were particularly related to those installations with a PW discharge <100,000 m3 yr-1.

To test how the proposed changes to DFs would impact screening of discharges at Tier 2, the installations that had an EIF less than 10 at Tier 3 and a PW discharge less than 125,000 m3 yr-1 during the first round of RBA were reviewed. The Tier 2 PNEC was recalculated using the proposed new DFs. The comparison is shown in Table 8.

Using the original DFs only two installations could be screened out at Tier 2 (PEC:PNEC ratio < 1). Once the ratio was recalculated using the new DFs nine installations could be screened out, which represents a significant increase in the number of installations being screened out at Tier 2. Although this is still conservative, given that all of these installations would have been screened out at Tier 3 during the first round of RBA, it does ensure than no installation is screened out too early (i.e. screened out at Tier 2 but with an EIF >10 at Tier 3).

Table 8: Comparison of PEC:PNEC ratio using old and new DFs

Installation	Water Depth (m)	Water depth below discharge (m)	PW discharge annual (m3 year)	Depth band	Volume band	DF	PEC:PNEC (new DFs)	PEC:PNEC with previous generic DFs
1	39.4	11.7	280	A	A	14000	9.11	12.82
2	21	9	395.5	A	A	14000	0.93	1.30
3	18.6	18.6	471	A	A	14000	0.42	0.59
4	39.8	13.8	603.5	A	A	14000	0.94	5.70
5	32	20.7	635	A	A	14000	0.94	1.54
6	34	23	1000	A	A	14000	4.00	5.60
7	34	23	1000	A	A	14000	4.49	6.30
8	23	23	1000	A	A	14000	0.38	0.53
9	23.5	11.5	1100	A	A	14000	3.02	4.20
10	95	95	4872	B	A	23000	0.57	1.30
11	34	27	10380	B	A	23000	0.68	1.56
12	105	90	12699	B	A	23000	1.18	2.70
13	37.6	30.6	13917	B	A	23000	0.85	1.96
14	29	29	18600	B	A	23000	2.91	6.68
15	90	80	19710	B	A	23000	2.79	6.40
16	31	3	24575	A	A	14000	2.20	3.10
17	116	116	32435	B	B	15000	2.14	3.21
18	19	19	44200	A	B	5000	9.85	4.90
19	89	79	84809	B	B	15000	0.97	1.53
20	43	28	100000	B	B	15000	4.17	6.30
21	43	28	100000	B	B	15000	3.38	5.10
Number installations that would be screened out at Tier 2							9	2
% installations that would be screened out at Tier 2							43%	10%

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