

## **APPENDIX J**

DREAM Model for Produced Water Release at the  
Bay du Nord Development (DeBlois 2020)

**Bay du Nord Development Project Environmental Impact Statement**



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TITLE

## **DREAM Model for Produced Water Release at the Bay du Nord Development**

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ABSTRACT

Six scenarios for produced water release were simulated. A produced water release rate of 30,000 m<sup>3</sup>/day was used for the first four cases; a release rate of 50,000 m<sup>3</sup>/day was used for the fifth and sixth cases. For the 30,000 m<sup>3</sup>/day scenarios, chemical profiles at OIW concentrations of 15 and 30 ppm were examined (Case 1 and Case 2, respectively). It was then assumed that produced water would be mixed with cooling water, which would result in dilution of the 15 and 30 ppm chemical profiles (Case 3 and Case 4, respectively). The remaining two scenarios examined the effect of increased produced water discharge to 50,000 m<sup>3</sup>/day at 30 ppm OIW concentrations, without mixing with cooling water (Case 5) and with mixing with cooling water (Case 6).

Case 5, representing the case with the largest produced water discharge volume, the highest OIW concentrations and no mixing with cooling water, was selected for detailed examination. Concentrations of OIW, some BTEX and 2-3 ring PAHs, and phenol (incl. C1-C3 alkyl phenols) occurred at concentrations above their no-effects concentration. For all of these, concentrations for Case 5 were highest within 100 m of discharge source, and higher concentrations were more common to the southeast and within the top 10 m of the water column. Within 100 m from discharge source, concentrations could exceed no-effects concentrations up to 40% of the time for OIW and up to 60% of the time for BTEX, 2-3 ring PAHs and phenol. All concentrations decreased with distance. From 100 to 400 m of discharge source, OIW concentrations could exceed no-effects concentrations 10 to 20% of the time; and from 400 m to 1 km, concentrations could exceed no-effects concentrations 5 to 10% of the time. For BTEX, 2-3 ring PAHs and phenol, concentrations could exceed no-effects concentrations 20 to 30% of the time from 100 to 400 m, 10 to 20% of the time from 400 m to 1 km, and 5 to 10% of the time from 1 to 2 km.

Case 5 represents the worst case scenario of the six cases. Therefore, estimates of the potential zone of influence of produced water constituents presented above can be regarded as conservative.

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## 1 Introduction

The purpose of this report is to examine the distribution of oil-in-water (OIW) and other constituents of the produced water discharge at the proposed Bay du Nord Development Project site using the Dose-Related Risk and Effects Assessment Model (DREAM) (see Appendix A for details on DREAM). DREAM was developed by SINTEF in Trondheim, Norway, and is readily used in Norway and internationally to assess the distribution of produced water. The model can be used to examine the distribution of individual constituents within a produced water plume by taking into account their physical properties. Relevant properties incorporated in simulations include: concentration on release, density, solubility, vapour pressure, degradation rate and oil to water partitioning coefficient.

Constituents examined in this report are those identified as relevant in OSPAR (2012). Special attention is given to OIW, but results are also presented for other constituents (see Section 2 for a full list of constituents examined). In all cases, constituent concentrations in the water column are compared to predicted no-effects concentrations (PNEC values) as provided in OSPAR (2014) to provide a spatial and temporal estimate of concentrations that exceeded no-effects concentrations (i.e., concentrations that might lead to an effect). OSPAR (2014) predicted no-effects concentrations are based on long-term laboratory toxicity tests, usually at three trophic levels (algae, zooplankton and fish). As such, they are general and can be used as a first gauge of potential effects.

DREAM simulations for produced water generally are carried out during times when biological resources are most vulnerable, either because of sensitivity of life stages or because of low turbulent mixing and possibility of higher levels of exposure, or both. This approach is conservative in that it provides worst-case-scenario estimates. In Norway, the month of May is simulated. In Newfoundland, wind speeds (which drive surface currents) are lowest in May, June, July and August. Average wind speeds in these months are 7.4 m/s, 6.9 m/s, 6.2 m/s and 6.7 m/s, respectively, versus 8 to 12 m/s in the remainder of the year (Fisheries and Oceans Canada MSC50 data at 47.9 Latitude and -46.4 Longitude for the period 1962 to 2015). With respect to turbulent mixing, any of these months could have been used for modeling. However, since most plankton would be in the water column in Spring, June (with the lowest wind speed of the two Spring months) was selected, in keeping with the worst-case scenario approach. Results of continuous discharge over 30 days in June are provided herein.

## 2 Bay du Nord Produced Water Release Scenarios

The release site for simulations was located at 46° 23' 0.887" W and 47° 57' 49.647" N within the core Bay du Nord Development Project Area (Figure 2.1).

Six modeling exercises were performed. The first four modelling exercises were performed at a discharge rate of 30,000 m<sup>3</sup>/day, with and without mixing with cooling water and OIW concentrations of either 15 ppm or 30 ppm. The 30 ppm scenarios represent the monthly target level for treated produced water discharge per the Offshore Waste Treatment Guidelines (National Energy Board et al. 2010). With the application of best available technology and optimal processing conditions, OIW concentrations may be reduced lower than the guideline level. The last two modelling exercises were performed at a discharge rate of 50,000 m<sup>3</sup>/day, with and without mixing with cooling water and at 30 ppm OIW concentrations. The 50,000 m<sup>3</sup>/day scenarios represent the maximum anticipated produced water discharge rate for the Bay du Nord Development Project. A summary of simulated scenarios is provided in Table 2-1.

Chemical profiles for the naturally occurring constituents in produced water represented at OIW concentrations of 15 and 30 ppm are provided in Table 2-2, as are PNEC values (after OSPAR 2014). Because information on produced water at Bay du Nord will not be available until produced water is released, chemical profiles are standard average profiles used by Equinor for new developments based on values observed at their existing developments.

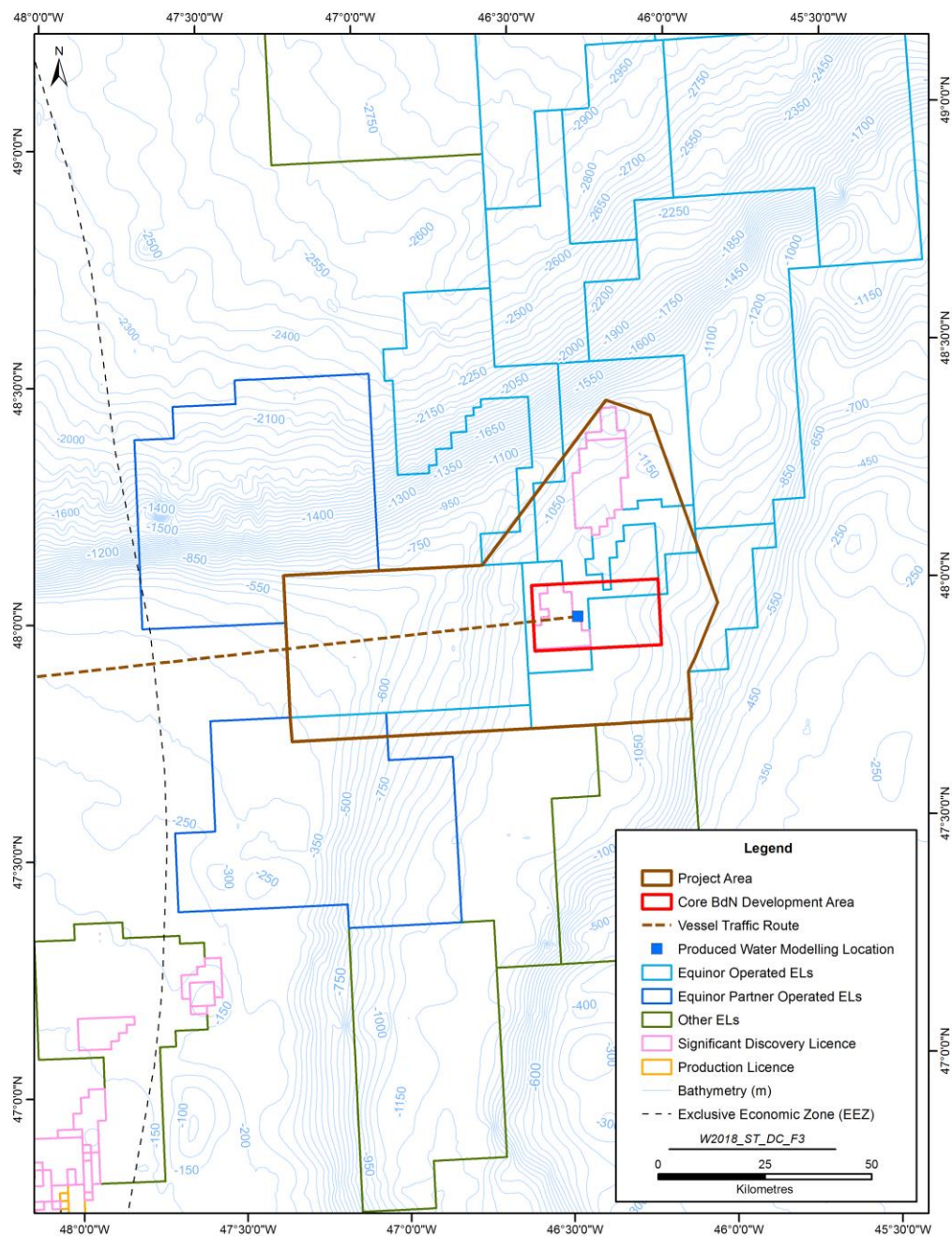


Figure 2-1 Bay du Nord Development Project Area and Produced Water Release Site Location

BdN = Bay du Nord  
EL = Exploration Licence

Table 2-1 Produced water release scenarios at Bay du Nord.

Variable	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
PW Flow (m <sup>3</sup> /day)	30,000	30,000	30,000	30,000	50,000	50,000
Cooling Water Flow (m <sup>3</sup> /day)	0	0	25,000	25,000	0	25,000
Total Flow of Release (m <sup>3</sup> /day)	30,000	30,000	55,000	55,000	50,000	75,000
PW OIW (ppm)	15	30	15	30	30	30
Depth of Release (m below sea surface)	20	20	20	20	20	20
Release Pipe Diameter	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m	0.6 m
Vertical Angle of Release	180°	180°	180°	180°	180°	180°
Temperature of Total Flow (°C)	40	40	37.7	37.7	40	40
Salinity of Total Flow (ppt)	33	33	33	33	33	33

Notes:

- PW = Produced water.
- Estimates were provided by Equinor.
- Temperatures for produced water and cooling water were 40 °C and 35 °C, respectively. Salinity was 33 ppt for both produced water and cooling water. In Table 2-1, temperature and salinity are weighted averages of produced water and cooling water temperature and salinity. Because salinity for produced water and cooling water was the same, salinity does not vary across cases.
- A 180° vertical angle of release is a downward release pipe.

Table 2-2 Chemical profiles of naturally occurring constituents in produced water for simulations.

Constituent Group	Constituent	Discharge Concentration (mg/L)	Discharge Concentration (mg/L)	PNEC values (µg/L)
<b>OIW</b>	OIW	<b>15</b>	<b>30</b>	<b>70.5</b>
<b>BTEX</b>	Benzene (and xylene)	8.40045	8.4004	<b>8</b>
	Toluene	5.08233	5.0823	<b>7.4</b>
	Ethylbenzene	0.31611	0.3161	<b>10</b>
<b>Naphthalene</b>	Naphthalene (and alkyl homologues)	0.92623	1.27820	<b>2</b>
<b>2-3 ring PAH</b>	Acenaphthylene	0.00111	0.00156	<b>0.13</b>
	Acenaphthene	0.00317	0.00448	<b>0.38</b>
	Fluorene	0.01227	0.01730	<b>0.25</b>
	Phenanthrene (and alkyl homologues)	0.08422	0.11875	<b>1.3</b>
	Anthracene (+dibenzothiophene and alkyl homologues)	0.03381	0.04767	<b>0.1</b>
<b>4 ring PAH</b>	Fluoranthene	0.00034	0.00051	<b>0.0063</b>
	Pyrene	0.00055	0.00081	<b>0.023</b>
	Chrysene	0.00990	0.00148	<b>0.007</b>
	Benz(a)anthracene	0.00018	0.00027	<b>0.0012</b>
<b>5-6 ring PAH</b>	Benzo[b]fluoranthene	0.00009	0.00014	<b>0.00017</b>
	Benzo[k]fluoranthene	0.00010	0.00014	
	Benzo(a)pyrene	0.00010	0.00015	
	Indeno[1,2,3-cd]pyrene	0.00001	0.00002	
	Benzo(g,h,i)perylene	0.00004	0.00006	
	Dibenzo(a,h)anthracene	0.00001	0.00002	<b>0.00014</b>
<b>Alkyl phenols</b>	Phenol (and C1-C3 alkyl phenols)	6.03395	6.03395	<b>7.7</b>
	Butylphenol (and other C4 alkyl phenols)	0.06160	0.06160	<b>0.64</b>
	Pentylphenol (and other C5 alkyl phenols)	0.02359	0.02359	<b>0.2</b>
	Octylphenol (and C6-C8 alkyl phenols)	0.00117	0.00168	<b>0.01</b>
	Nonylphenol (and other C9 alkyl phenols)	0.00006	0.00008	<b>0.3</b>
<b>Metals</b>	Cadmium (Cd)	0.000013	0.000013	<b>0.21</b>
	Zinc (Zn)	0.003583	0.003583	<b>3.4</b>
	Copper (Cu)	0.001048	0.001048	<b>2.6</b>
	Lead (Pb)	0.000082	0.000082	<b>1.3</b>
	Nickel (Ni)	0.000617	0.000761	<b>8.6</b>
	Mercury (Hg)	0.000004	0.000004	<b>0.048</b>
	Arsenic (As)	0.000068	0.000068	<b>0.6</b>
Chromium (Cr)	0.000438	0.000438	<b>0.6</b>	

Notes:

- Discharge concentrations were provided by Equinor.
- PNEC values are from OSPAR (2012, 2014).
- BTEX = Benzene, toluene, ethylbenzene and xylene.
- PAH = Polycyclic aromatic hydrocarbons.

### 3 Met-Ocean Inputs

Met-Ocean inputs were assembled by Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited (Wood).

Among the other characteristics of DREAM that may differ from previously submitted produced water modelling exercises, is the use of a current time-series rather than average, high or low current values at a range of depths (i.e., DREAM is dynamic rather than static; current variations within the course of the simulated month are accounted for).

For produced water modelling, the best available current speed and direction time-series measurements for the Bay du Nord Development Project Area were from a current mooring equipped with Acoustic ADCP<sup>1</sup> and RCM<sup>2</sup> instruments deployed from July 2014 to May 2016<sup>3,4</sup>. Current data for June 2015 were selected to be representative of current conditions for June. Current measurements from 21 depths ranging from 25 to 531 m were used. Currents at 25 m were applied to 0 to 25 m depths layers for modelling. An inspection at HYCOM modelled (daily) currents suggests speeds will be larger closer to the surface than at 25 m (see Appendix B for details). Since larger current speeds would result in increased dilution, using the lower currents speeds measured at 25 m in this modelling exercise is consistent with a conservative approach.

Water mass characteristics (temperature and salinity) for June were based on monthly statistics derived from the hydrographic database of the Ocean Data Inventory of the Bedford Institute of Oceanography.

Further details on currents, temperature and salinity data are provided in Appendix B.

### 4 Model Parameters

The plume was modelled over an area of 20 x 20 km, by 100 m (depth). A deeper modelling window was not required because the plume did not extend beyond 100 m. Cell size was 100 x 100 m, by 10 m (depth). Cell size determines the spatial resolution of the model. Time-step was set at 5 minutes with an output interval every 6 hours.

### 5 Model Output

Model output was used to generate maps of the total concentration of constituents in Table 2-2 over the entire modelled area. These maps are a snapshot in time over 30 days of a continuous discharge. They are meant to provide examples of the general behaviour/distribution of the plume on the selected days. Case 5, representing the plume with the largest produced water discharge volume, the highest OIW concentrations and no mixing with cooling water was selected for display in the main body of the report, with snapshot maps for all cases provided in Appendix C. These large

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<sup>1</sup> Acoustic Doppler Current Profiler.

<sup>2</sup> Recording Current Meter.

<sup>3</sup> It has been noted previously that use of a single point time series rather than a 3-dimensional representation of the current field removes additional dilution by horizontal and vertical shears, likely contributing to an increase in concentrations (Mark Reed, pers. comm.).

<sup>4</sup> These input currents for the model provide variability in the vertical with horizontal currents assumed to be uniform. The vertical and horizontal current shears likely to be encountered would provide additional dilution to the produced water plume. In this way the concentration predictions presented here may be somewhat conservative (high) (John McClintock, pers. comm.).

scale snapshots were also generated for OIW concentrations, with all cases presented in Appendix D.

Model output was then used to generate probability maps for each constituent listed in Table 2-2. Case 5 was again selected for detailed display with maps for all cases in Appendix E. This second set of maps express the probability that each constituent will exceed no-effects thresholds (OSPAR PNEC values), as listed in Table 2-2<sup>5</sup>. The probability that a constituent will exceed threshold, expressed as a percentage, is equivalent to a percent (%) occurrence over the course of the 30-days simulation period. Maps were also generated for the groups: BTEX, 2-3 ring PAHs and 4-6 ring PAHs, for practical reasons. These groups represent compounds of concern within produced water and with similar physico-chemical and toxicological properties (OSPAR 2014, OSPAR 2012, Neff et al. 2011). For these groups, the no-effects threshold was calculated as a weighted average of the predicted no-effects thresholds (OSPAR PNECs) of constituents in each group<sup>6</sup>.

Because this generated a large number of maps even just for Case 5, a subset of these maps was selected for presentation in the main report, with all maps provided in Appendix E. In general, maps of constituents, or constituent groups, that indicated that that no-effects threshold could be exceeded were presented in the main body of this report. Finally, for those selected constituent or constituent groups, maps of maximum concentrations were generated. These last maps express maximum concentrations over the entire water column at the time when the plume was most concentrated (i.e., concentrations were highest). For Case 5, the worst of the six cases and the one highlighted below, maximum concentrations occurred on day 3, at 06:00 hrs.

## 6 Simulation Results

### 6.1 General distribution of the PW plume

The produced water plume most often extended to the southeast or south (Figures 6-1 to 6-6). It was generally restricted to the upper 50 m of the water column, with higher concentrations in the first 10 m near discharge source. Case 5, representing the plume with the largest produced water discharge volume, the highest OIW concentrations and no mixing with cooling water was selected for further display of the evolution of the plume. Days 5, 10, 15, 20, 25 and 30 at different depths are shown in Figures 6-1 to 6-6, respectively. These figures represent a snapshot in time over 30 days of a continuous discharge. They are meant to provide examples of the general behaviour/distribution of the plume on the selected days. On day 5, for instance, currents were predominantly to the south; whereas on day 25, currents were predominantly to the southeast. The total plume for remaining

<sup>5</sup> Probability over threshold for any given cell is calculated as the number of model outputs above a threshold in that cell over the total number of outputs in a 30-day simulation X 100.

<sup>6</sup>Weighted PNECs for BTEX, 2-3 ring PAHs and 4-6 ring PAHs were 8.82 µg/L, 1.86 µg/L and 0.0091 µg/L, respectively. A weighted arithmetic average is similar to an ordinary arithmetic average except that instead of each of the data points contributing equally to the final average, some data points contribute more than others. In this case, PNECs were 'weighted' by the relative concentration of each constituent within the group, giving a higher weight to the PNEC values for constituents that occurred at higher concentrations. For instance, within the BTEX group, benzene had the highest concentration (8.4 mg/L) and the total concentration of BTEX was 13.8 mg/L. The weight for BTEX is then  $8.4/13.8 = 0.61$ . This weight is then applied to the PNEC value of 8 µg/L which gives a weighted PNEC value of 4.88 µg/L. The sum of these weighted values for each constituent within the group is then the weighted PNEC value for the group. Because concentrations of some constituents differed slightly between the 15 ppm and the 30 ppm OIW chemical profiles, this generated slightly different weighted PNEC values for each of the two chemical profiles provided in Table 2-2. The average of these two values was used as the threshold for the groups.

cases behaved as did the plume for Case 5. Day 10, 20 and 30 at different depths for all six cases are provided in Appendix C.

OIW concentrations for Cases 1 to 6 on days 10, 20 and 30 at different depths are provided in Appendix D. At this scale, there is no marked difference between the distribution of OIW and the distribution of the total plume (as shown in Figures 6-1 to 6-6); nor are there marked differences among the six cases. As was the case for the total plume, concentrations were highest in the first 10 m of the water column, near discharge source. More detail on the spatial distribution of OIW with respect to no-effects threshold concentrations are provided in Section 6.2.1.

## **6.2 Near-field concentrations and probability of exceedance of toxicity thresholds**

Remaining figures in this report focus on the near-field where concentrations may exceed no-effects threshold concentrations. Depth integrated probability maps and near-field maximum concentrations for OIW, BTEX, 2-3 ring PAHs and phenol (including C1-C3 alkyl phenols) are shown in Figure 6-7 to 6-10. Whereas the figures discussed in Section 6.1 represented snap-shots in time, probability maps (panel A in Figures 6-7 to 6-10) integrate results over the entire simulation window (30 days) and indicate the probability that produced water constituents will occur over the thresholds listed in Table 2-2. Maximum concentration maps (panel B in Figures 6-7 to 6-10) are snap-shots in time on the day and time when the plume was most concentrated.

As was done for snap-shots of the entire plume in Figures 6-1 to 6-6, Case 5 is selected for display below. Probability maps for all cases are provided in Appendix E. A general comparison among the six cases is provided in Section 6.2.6.

### **6.2.1 Oil-in-Water**

The probability that OIW concentrations will exceed the threshold concentration (PNEC) of 70.5 µg/L for Case 5 is provided in Figure 6-7. At maximum discharge rate (50,000 m<sup>3</sup>/day), maximum OIW concentration (30 ppm) and no mixing with cooling water, OIW concentrations within 100 m from discharge source could exceed threshold up to 40% of the time. From approximately 100 to 400 m, concentrations could exceed threshold 10 to 20% of the time; and from 400 m to 1 km, concentrations could exceed threshold 5 to 10 % of the time<sup>7</sup>. Higher concentrations occurred to the southeast of discharge source and most concentrations over threshold occurred in the top 10 m of the water column (see Appendix F for depth profiles for Case 5).

### **6.2.2 BTEX**

The probability that concentrations will exceed threshold was higher for BTEX (Figure 6-8). Benzene and xylene accounted for most of this, toluene accounted for less, and ethylbenzene concentrations alone did not exceed threshold concentrations (see Appendix E for probability maps for benzene and xylene, toluene and ethylbenzene). Within 100 m from discharge source, BTEX concentrations could exceed the threshold of 7.83 µg/L up to 60% of the time. Probabilities were in the 20 to 30% range from approximately 100 to 400 m from source; in the 10 to 20% range from approximately 400 m to 1 km; and in the 5 to 10% range from approximately 1 to 2 km. Higher concentrations occurred to the southeast and most concentrations over threshold occurred in the top 10 m of the water column (see Appendix F for depth profiles for Case 5).

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<sup>7</sup> These estimates of potential exposure represent episodic events over the course of the month. An estimate of 10%, for example, represents exposure for a total of three days over the month. However, this exposure is not continuous over those three days.

### 6.2.3 2-3 ring PAHs

For 2-3 ring PAHs, concentrations over the threshold of 1.86 µg/L could occur up to 60% of the time within 100 m from discharge source (Figure 6-9). Probabilities were in the 20 to 30 % range from approximately 100 to 400 m from source; in the 10 to 20% range from 400 m to 1 km; and in the 5 to 10% range from approximately 1 to 2 km. Higher concentrations occurred to the southeast and most concentrations over threshold occurred in the top 10 m of the water column (see Appendix F for depth profiles for Case 5). For this group, naphthalene and anthracene contributed most to these results. The probability of occurrence for phenanthrene was extremely low, with a predicted occurrence of up to 5% at some locations within 1 km from source. Remaining PAHs within this group (acenaphthylene, acenaphthene and fluorene) did not occur at concentrations over threshold (see Appendix E for probability maps for all constituents).

### 6.2.4 Phenol (and C1-C3 alkyl phenols)

For phenols, concentrations exceeding the threshold of 7.7 µg/L could occur up to 60% of the time within 100 m from discharge source (Figure 6-10). Probabilities were in the 20 to 30 % range from approximately 100 to 400 m from source; in the 10 to 20% range from approximately 400 m to 1 km; and in the 5 to 10% range from approximately 1 to 2 km. Higher concentrations occurred to the southeast and most concentrations over threshold occurred in the top 10 m of the water column (see Appendix F for depth profiles for Case 5).

### 6.2.5 Remaining PW constituents

Of remaining constituents in Table 2-2, only butylphenol (and other C4 alkyl phenols) concentrations exceeded its threshold concentration. The concentration of butylphenol (and other C4 alkyl phenols) could exceed threshold concentrations up to 5% of the time at some locations within approximately 1 km from discharge source. All 4 ring and 5-6 ring PAHs, C5, C6-C8 and C9 alkylphenols and all metals did not exceed their respective threshold concentrations (Appendix E).

### 6.2.6 Release scenario comparison

Probability of occurrence above no-effects thresholds for OIW for all six cases is provided in Figure 6-11. At 15 ppm OIW concentration (Cases 1 and 3), the footprint of oil concentrations above threshold in the water column was less than half that of Cases 2 and 4 (each at 30 ppm and comparable discharge volumes). As expected, comparison of these cases indicates that a decrease in OIW content in produced water will lead to a decrease in the footprint of oil concentrations over threshold.

Cases 5 and 6 relative to Cases 2 and 4, respectively, assess the influence of increased produced water discharge volume to 50,000 m<sup>3</sup>/day. Increased produced water discharge volume increases the footprint of oil concentrations over threshold.

Cases 3, 4 and 6 relative to Cases 1, 2 and 5, respectively, assess the influence of mixing the produced water discharge with cooling water - effectively diluting the produced water discharge. In general, mixing with cooling water reduces the footprint of OIW concentrations over threshold, with this reduction most apparent for Cases 1 versus 3 (Figure 6-11). However, the difference is not as apparent for Cases 2 versus 4, or Cases 5 versus 6. In these instances, it is probable that the higher plume volume caused produced water to expand over a larger area and, with an initial OIW concentration of 30 ppm, many model cells remained above threshold. These results will vary for each constituent depending on their initial concentrations and respective thresholds and constituents with low no-effects thresholds may show little change across the six cases. However, in general and as would be expected, mixing with cooling water decreases concentrations of constituents.

### 6.3 Summary and discussion

Six scenarios for produced water release at the proposed Bay du Nord development were simulated. A produced water release rate of 30,000 m<sup>3</sup>/day was assumed for the first four cases; a release rate of 50,000 m<sup>3</sup>/day was assumed for the fifth and sixth cases. For the 30,000 m<sup>3</sup>/day scenarios, chemical profiles at OIW concentrations of 15 and 30 ppm were examined (Case 1 and Case 2, respectively). It was then assumed that produced water would be mixed with cooling water, which would result in dilution of the 15 and 30 ppm chemical profiles (Case 3 and Case 4, respectively). The remaining two scenarios examined the effect of increased produced water discharge to 50,000 m<sup>3</sup>/day at 30 ppm OIW, without mixing with cooling water (Case 5) and with mixing with cooling water (Case 6).

The general behaviour of the plume was similar for all six cases. The plume most often extended to the southeast or south and was generally restricted to the upper 50 m of the water column, with higher concentrations in the first 10 m near discharge source.

The near-field distribution of produced water constituents was examined for all cases; and maps of the probability of occurrence above no-effects thresholds were generated. Case 5, with the highest discharge volume, the higher OIW concentration and no mixing with cooling water was selected for detailed examination.

Of constituents examined, OIW, some BTEX and 2-3 ring PAHs, and phenol (including C1-C3 alkyl phenols) had the higher probability of occurrence over no-effects thresholds. For all these constituents, higher concentrations occurred to the southeast of discharge source and in the top 10 m of the water column. Remaining constituents had zero or near-zero probability of occurrence over no-effects thresholds.

Results for Case 5 indicated that OIW concentrations could exceed the no-effects threshold of 70.5 µg/L up to 40% of the time within 100 m from discharge source. From approximately 100 to 400 m, concentrations could exceed threshold 10 to 20% of the time; and from 400 m to 1 km, concentrations could exceed threshold 5 to 10 % of the time.

Case 5 results for BTEX, 2-3 ring PAHs and phenol were generally similar. Concentrations of each of these could exceed no-effects thresholds up to 60% of the time within 100 m from discharge source. As was the case for OIW, probability of occurrence over thresholds decreased with distance from discharge source, with probability of occurrence over threshold in the 20 to 30% range from 100 to 400 m, in 10 to 20% range from 400 m to 1 km, and in the 5 to 10% range from 1 to 2 km. Benzene and xylene accounted for most of the results for BTEX, toluene accounted for less, and ethylbenzene concentrations alone did not exceed threshold concentrations. For 2-3 ring PAHs, naphthalene and anthracene accounted for most of the results. The probability of occurrence for phenanthrene was extremely low, with a predicted occurrence of up to 5% of the time at some locations within 1 km from source. Remaining PAHs within this group (acenaphthylene, acenaphthene and fluorene) did not occur at concentrations over threshold.

As noted above, Case 5 was selected for a more detailed examination because the case had the highest discharge rate, the highest OIW concentration (and associated chemical profile) and no mixing with cooling water. Case 5 was the worst of the six cases tested and estimates of the potential zone of influence of produced water constituents discussed here can be regarded as conservative.

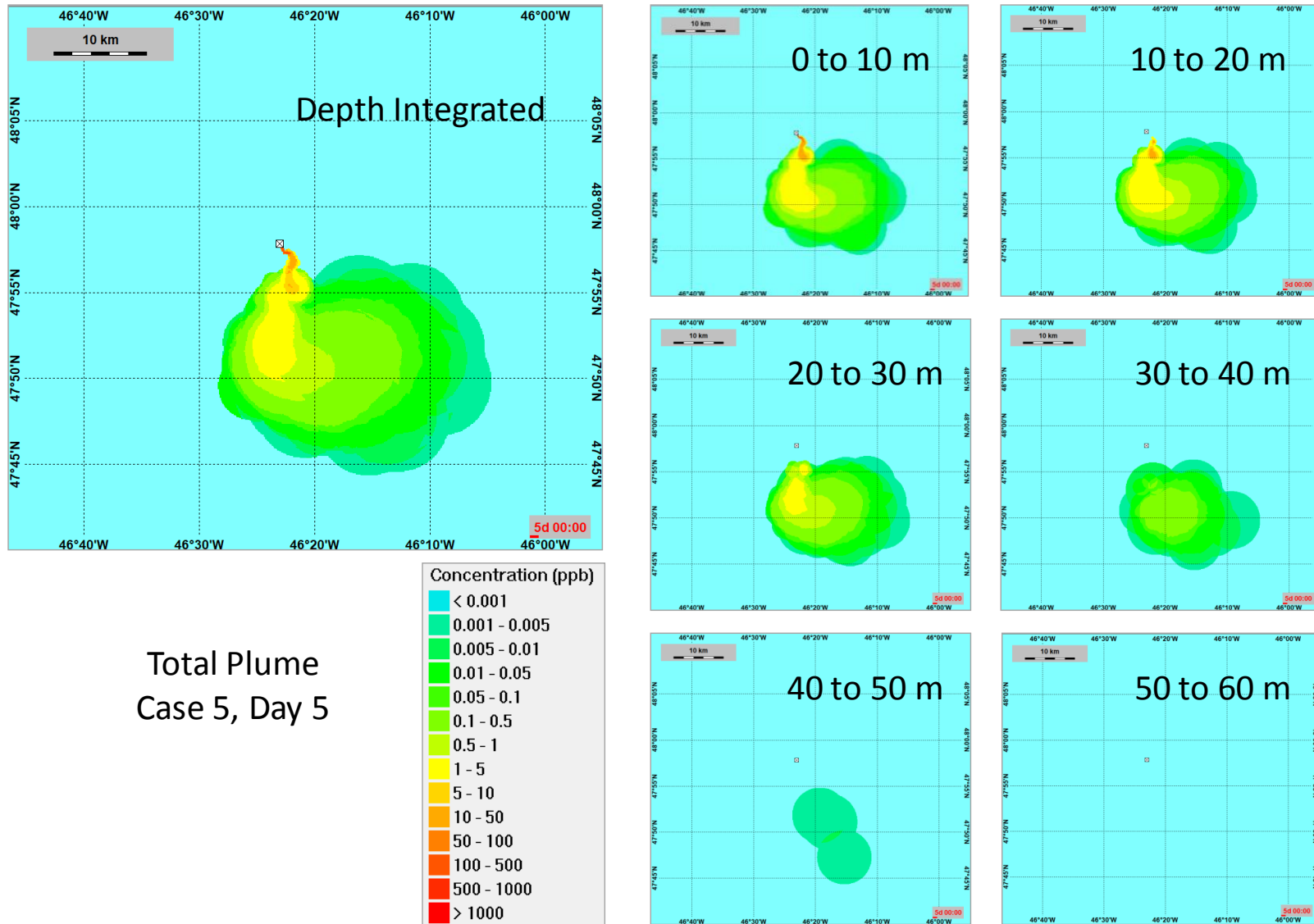


Figure 6-1 Case 5: Distribution of the PW plume on day 5 over the entire water column and at different depths.

This figure represents a snapshot in time over 30 days of continuous discharge. Concentration is total concentration of all constituents in the plume.

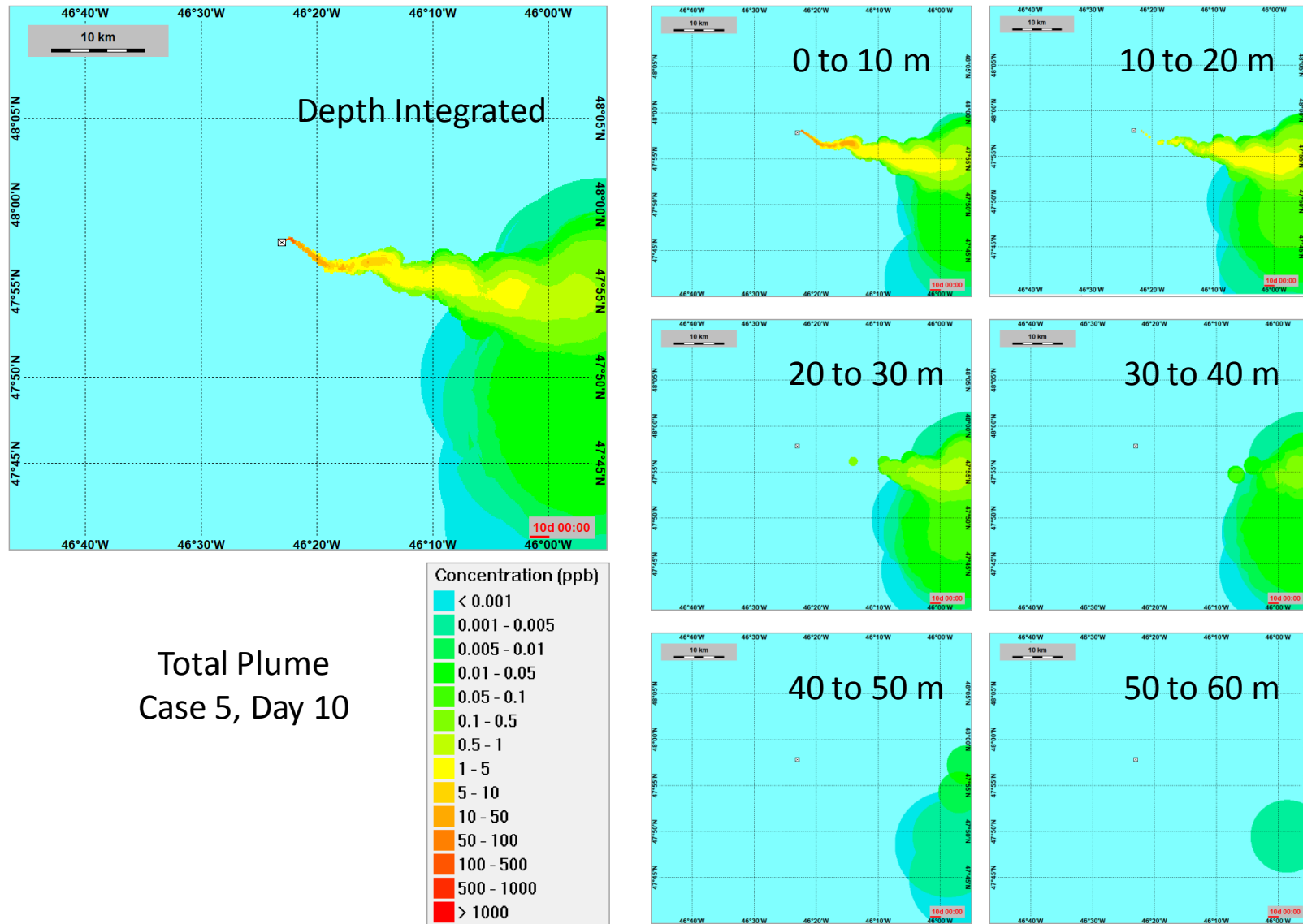


Figure 6-2 Case 5: Distribution of the PW plume on day 10 over the entire water column and at different depths.

This figure represents a snapshot in time over 30 days of continuous discharge. Concentration is total concentration of all constituents in the plume. Low concentration 'bubbles' in the far field here and elsewhere are caused by single numeric particles with very low mass and should be considered noise (Ute Brönnner, pers. comm.)

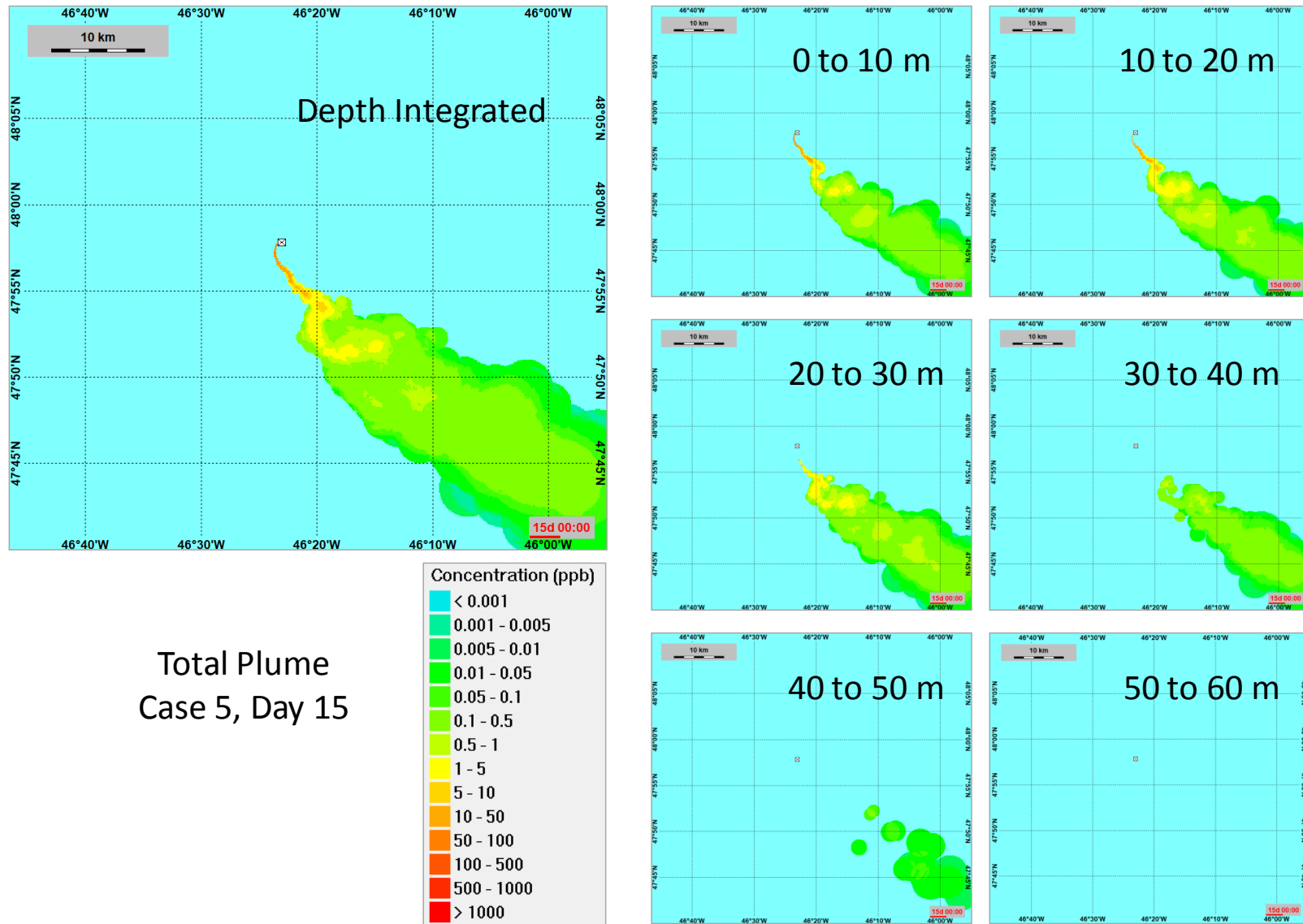


Figure 6-3 Case 5: Distribution of the PW plume on day 15 over the entire water column and at different depths.

This figure represents a snapshot in time over 30 days of continuous discharge. Concentration is total concentration of all constituents in the plume.

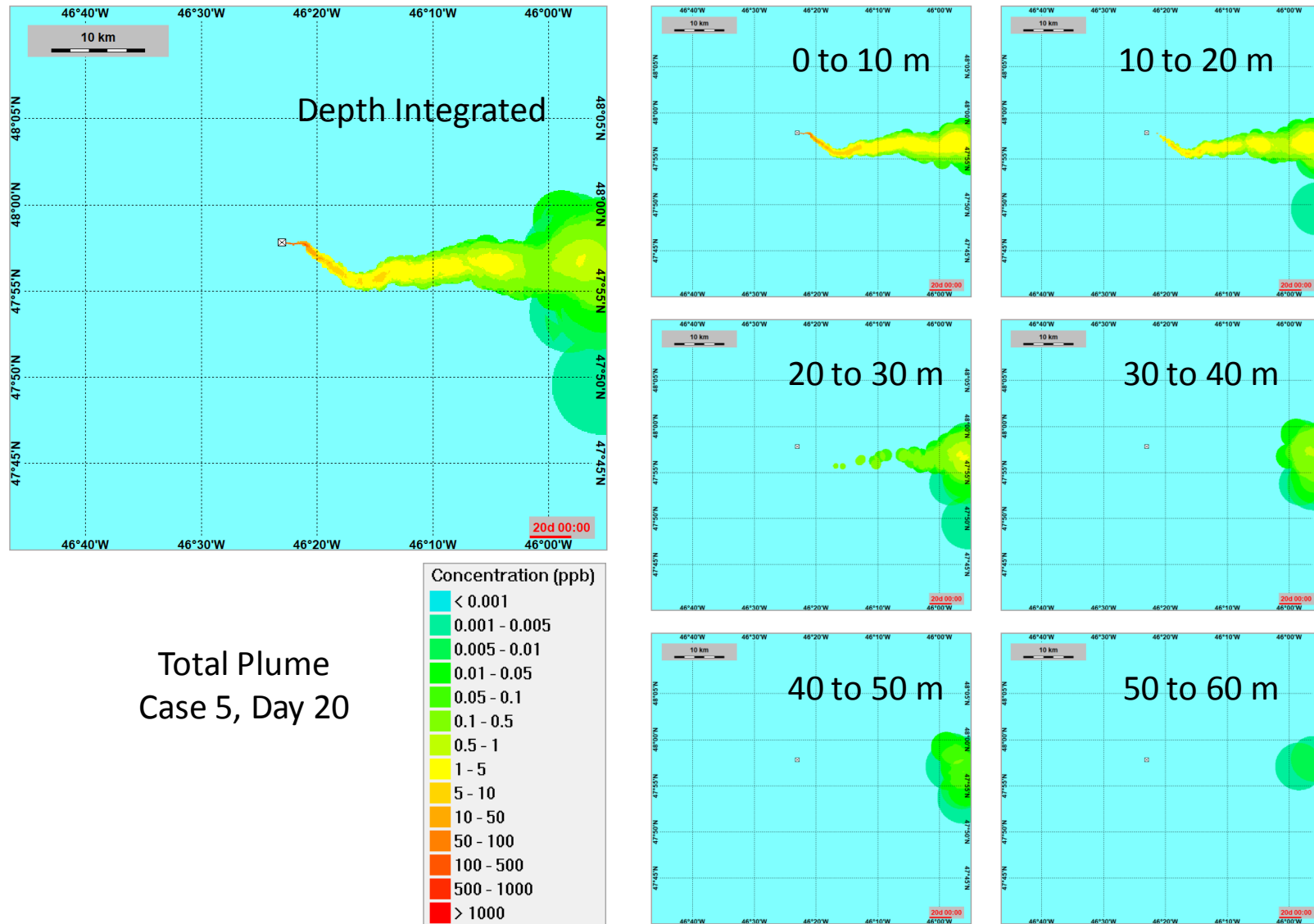


Figure 6-4 Case 5: Distribution of the PW plume on day 20 over the entire water column and at different depths.

This figure represents a snapshot in time over 30 days of continuous discharge. Concentration is total concentration of all constituents in the plume.

Low concentration 'bubbles' in the far field here and elsewhere are caused by single numeric particles with very low mass and should be considered noise (Ute Brønner, pers. comm.)

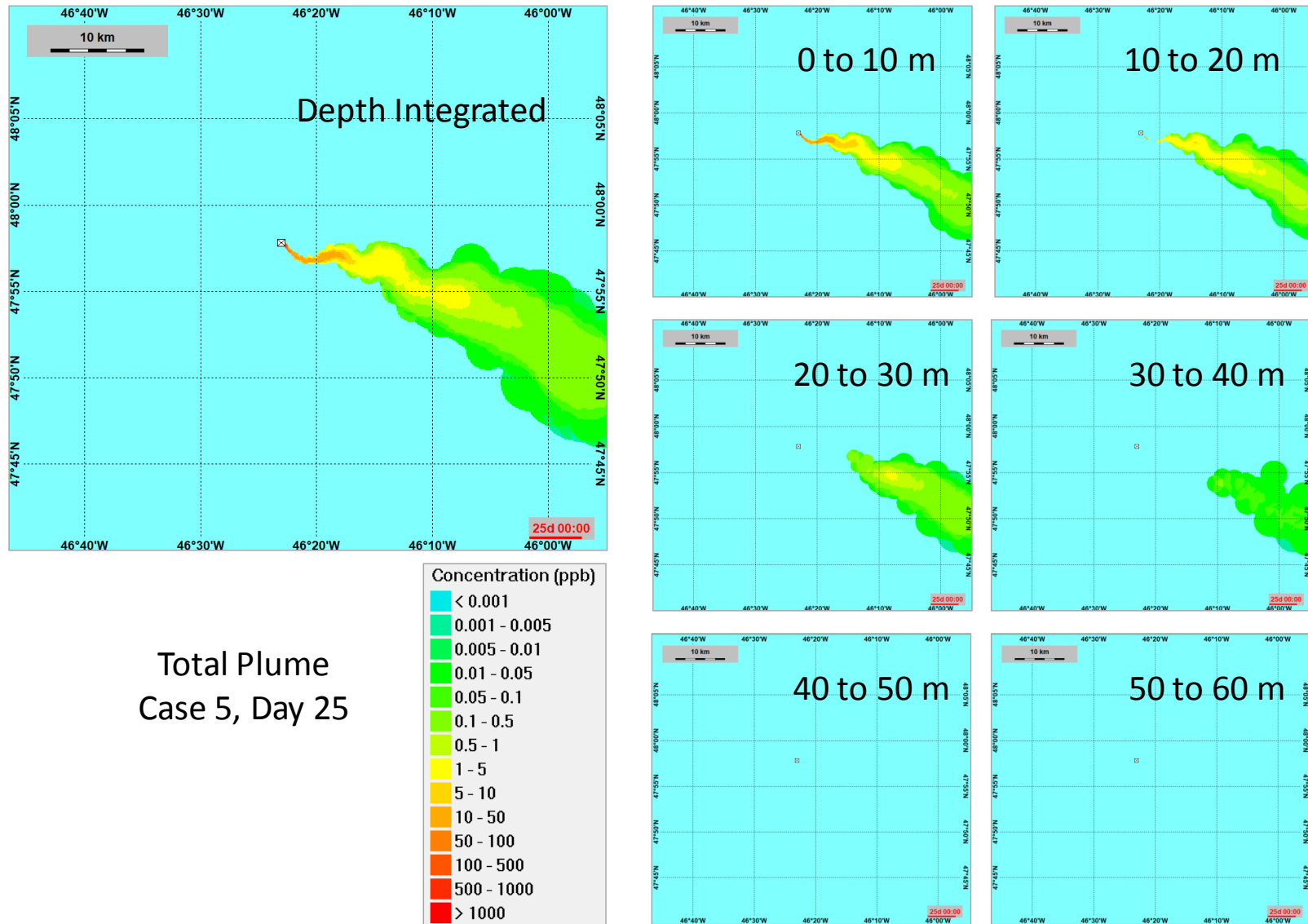


Figure 6-5 Case 5: Distribution of the PW plume on day 25 over the entire water column and at different depths.

This figure represents a snapshot in time over 30 days of continuous discharge. Concentration is total concentration of all constituents in the plume.

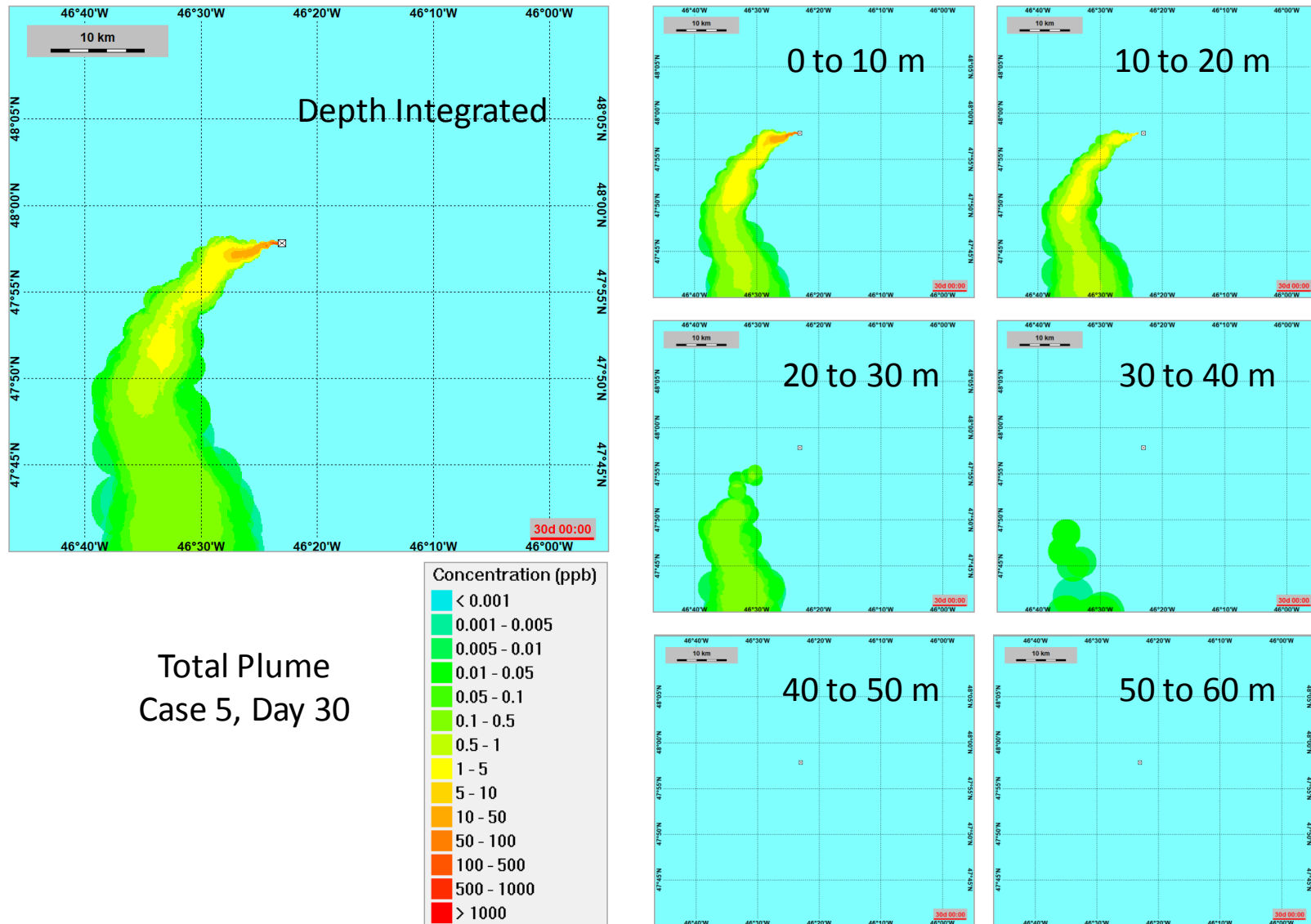


Figure 6-6 Case 5: Distribution of the PW plume on day 30 over the entire water column and at different depths.

This figure represents a snapshot in time over 30 days of continuous discharge. Concentration is total concentration of all constituents in the plume.

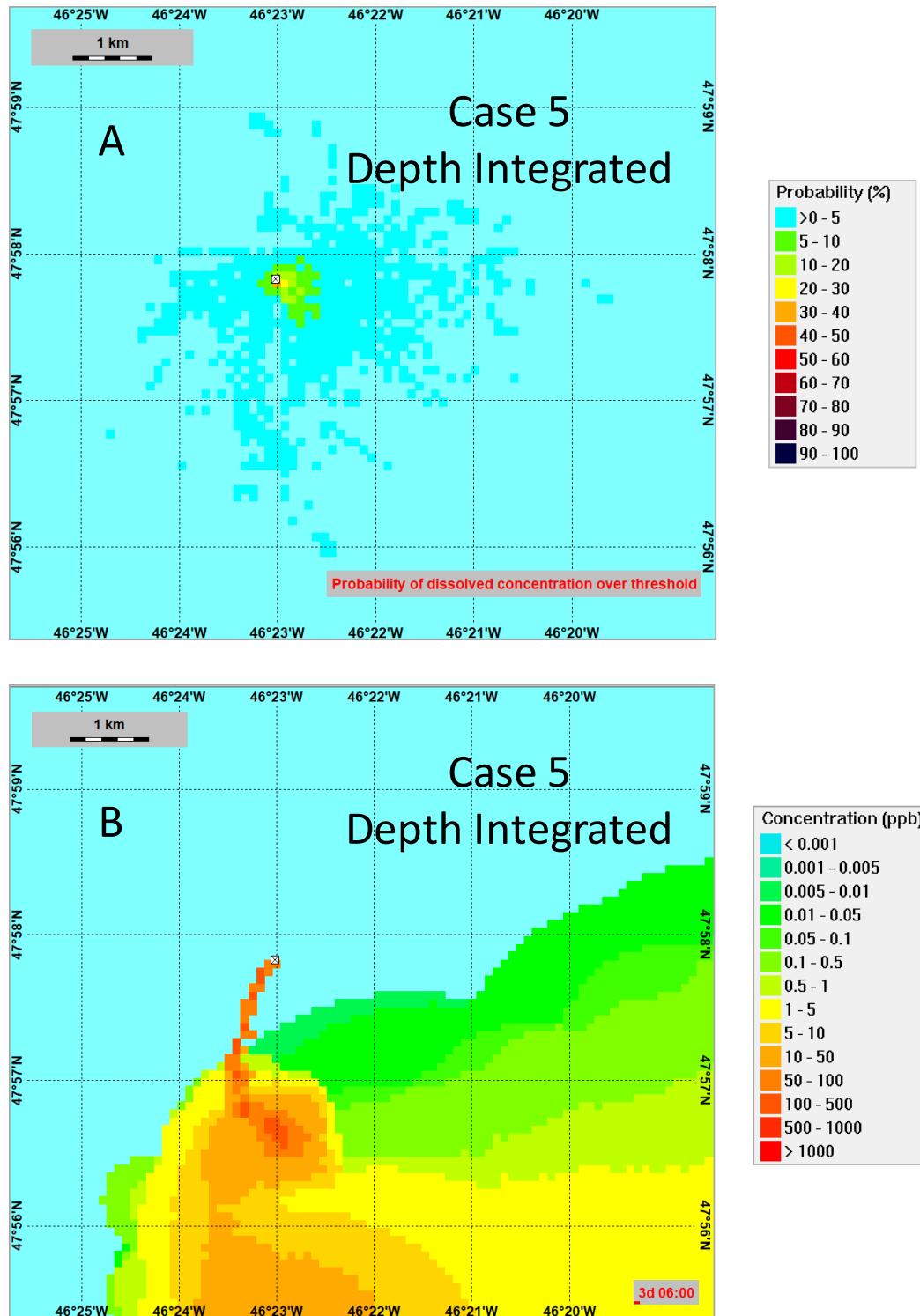


Figure 6-7 A) Probability that OIW will exceed the threshold concentration (PNEC) of 70.5  $\mu\text{g/L}$  based on a 30-day simulation, and B) Maximum OIW concentrations in the near-field when concentrations were highest during a 30-day simulation.

Panel A integrates the entire simulation period; Panel B represents concentrations on day 3 at 6:00 hrs.

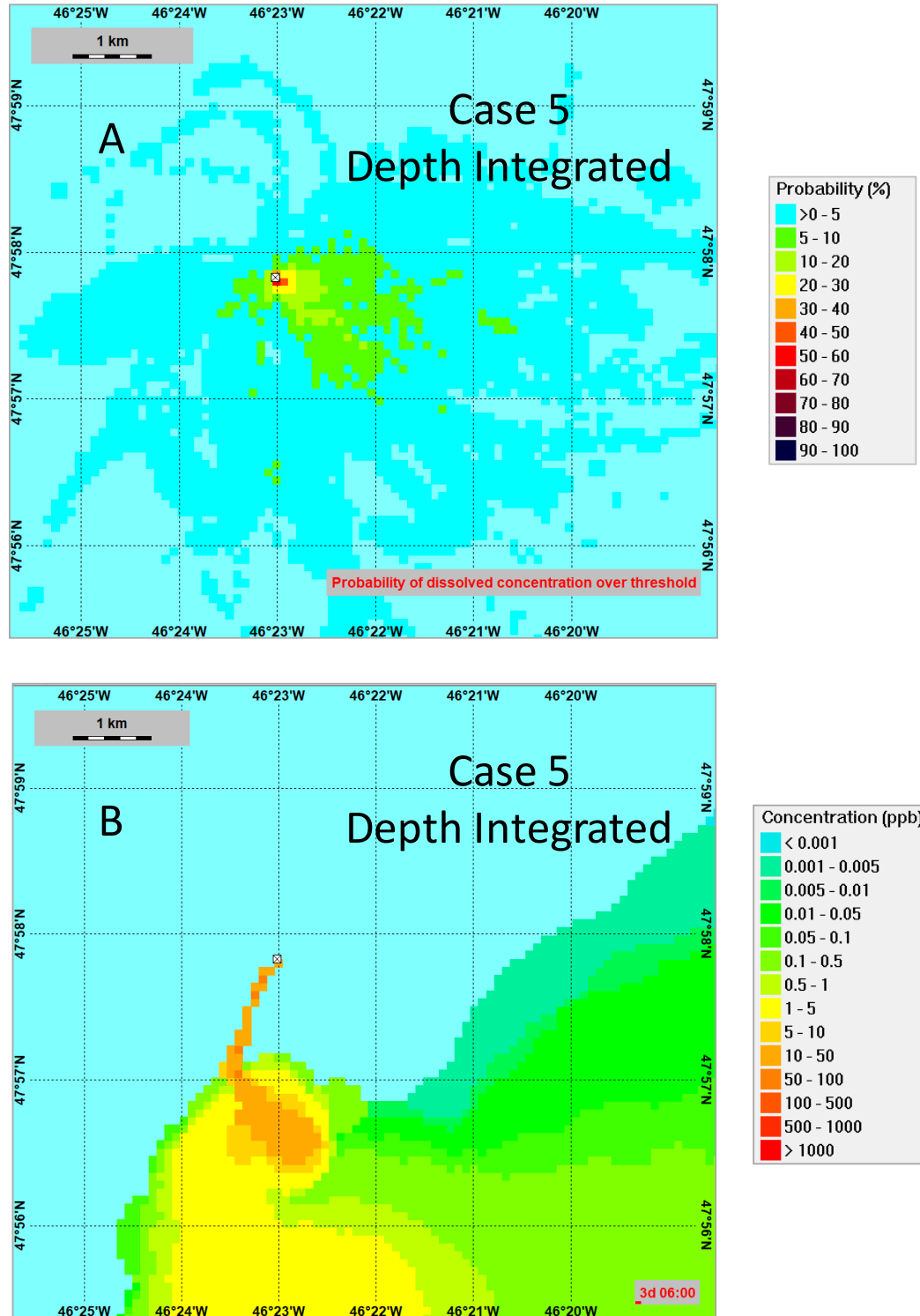


Figure 6-8 A) Probability that BTEX will exceed a no-effects concentration (PNEC) of 7.83  $\mu\text{g/L}$  based on a 30-day simulation, and B) Maximum BTEX concentrations when near-field concentrations were highest during a 30-day simulation.

Panel A integrates the entire simulation period; Panel B represents concentrations on day 3 at 6:00 hrs.

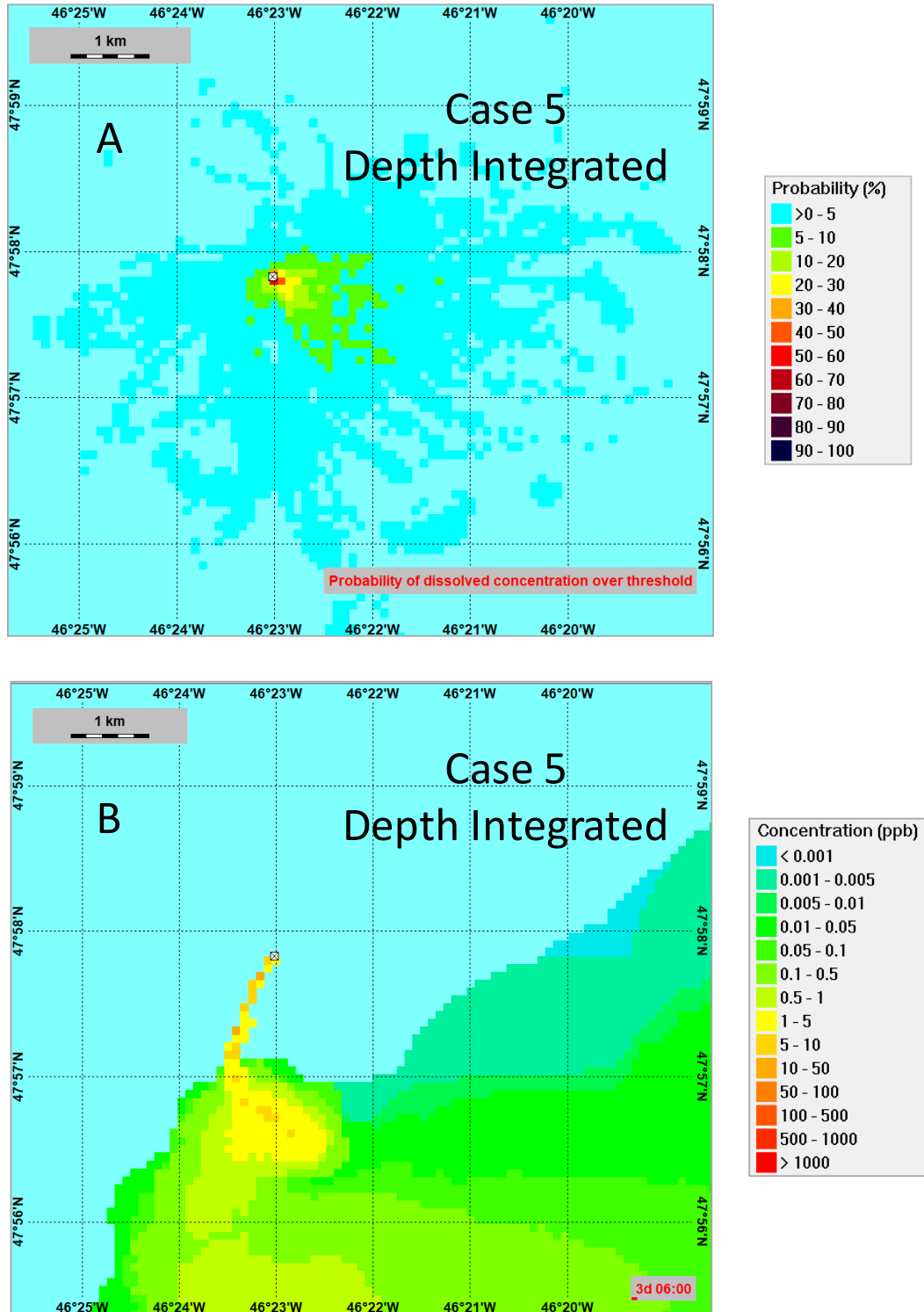


Figure 6-9 A) Probability that 2-3 ring PAHs will exceed a no-effects concentration (PNEC) of  $1.86 \mu\text{g/L}$  based on a 30-day simulation, and B) Maximum 2-3 ring PAH concentrations when near-field concentrations were highest during a 30 day simulation.

Panel A integrates the entire simulation period; Panel B represents concentrations on day 3 at 6:00 hrs.

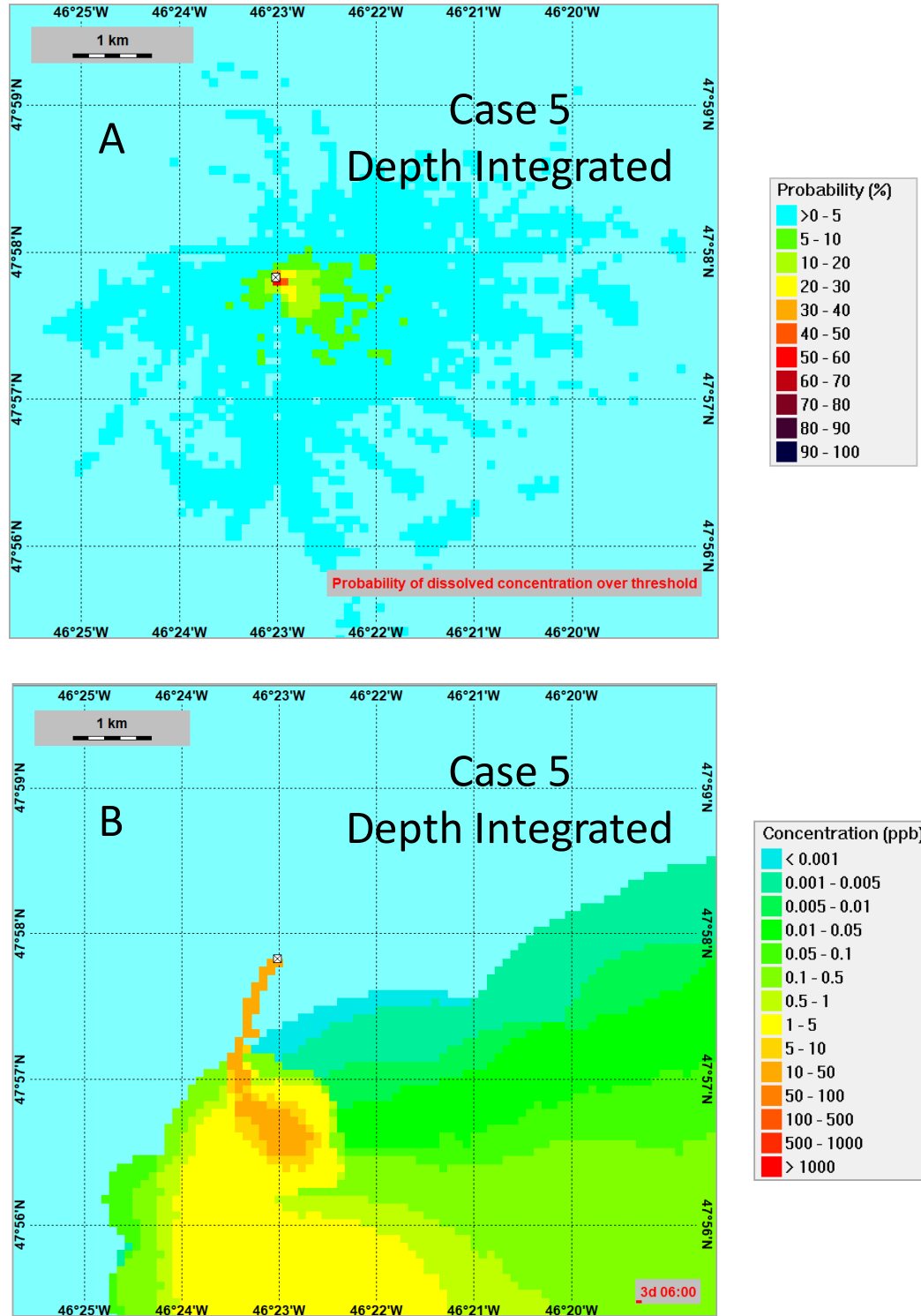


Figure 6-10 A) Probability that phenol (and C1-C3 alkyl phenols) will exceed a no-effects concentration (PNEC) of 7.7  $\mu\text{g/L}$  based on a 30-day simulation, and B) Maximum phenol (and C1-C3 alkyl phenols) concentrations when near-field concentrations were highest during a 30 day simulation.

Panel A integrates the entire simulation period; Panel B represents concentrations on day 3 at 6:00 hrs.

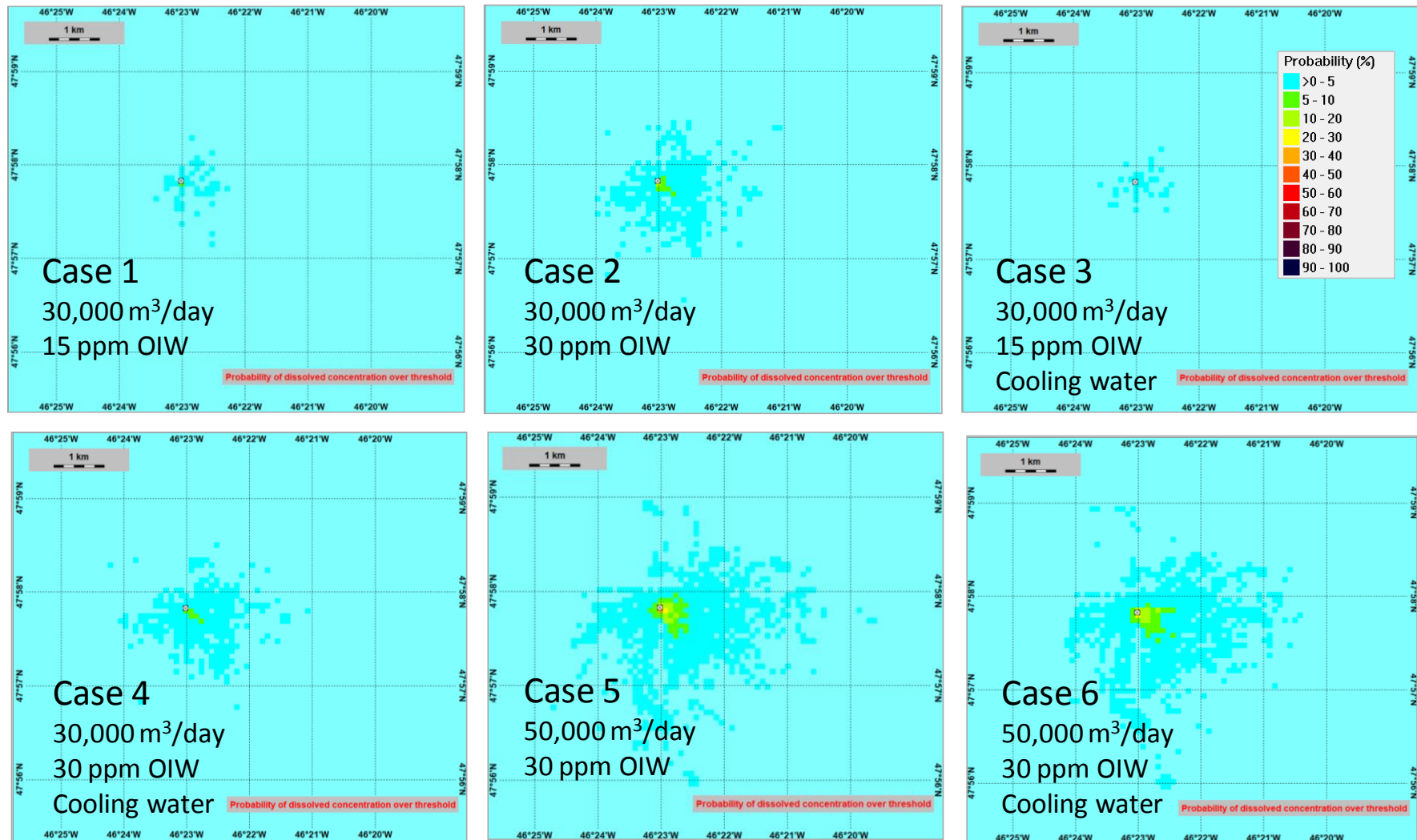


Figure 6-11 Probability that OIW will exceed a no-effects concentration (PNEC) of 70,5 µg/L. based on a 30-day simulation for Cases 1 to 6.

## 7 References

### 7.1 Personal Communication

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