19 APPENDICES

Appendix 1 – Technical Memorandum Mid-water Discharge and the Mesopelagic Zone

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DeepGreen

Technical Memorandum

Midwater Discharge and the Mesopelagic Zone

1. Introduction

DeepGreen has requested Dr Adrian Flynn of Fathom Pacific Pty Ltd to contribute an opinion regarding the depth selected for modelling of the midwater discharge as it relates to the ecology of the mesopelagic and bathypelagic zones.

The following information basis was provided to inform this opinion:

- A driver for the design specification of the midwater outfall is the minimisation of potential impacts in the mesopelagic zone.
- A vertical discharge is currently being considered and preliminary modelling has shown that a midwater discharge beyond a certain depth has the potential to generate a down-force that is sufficient to potentially resuspend bottom sediments.

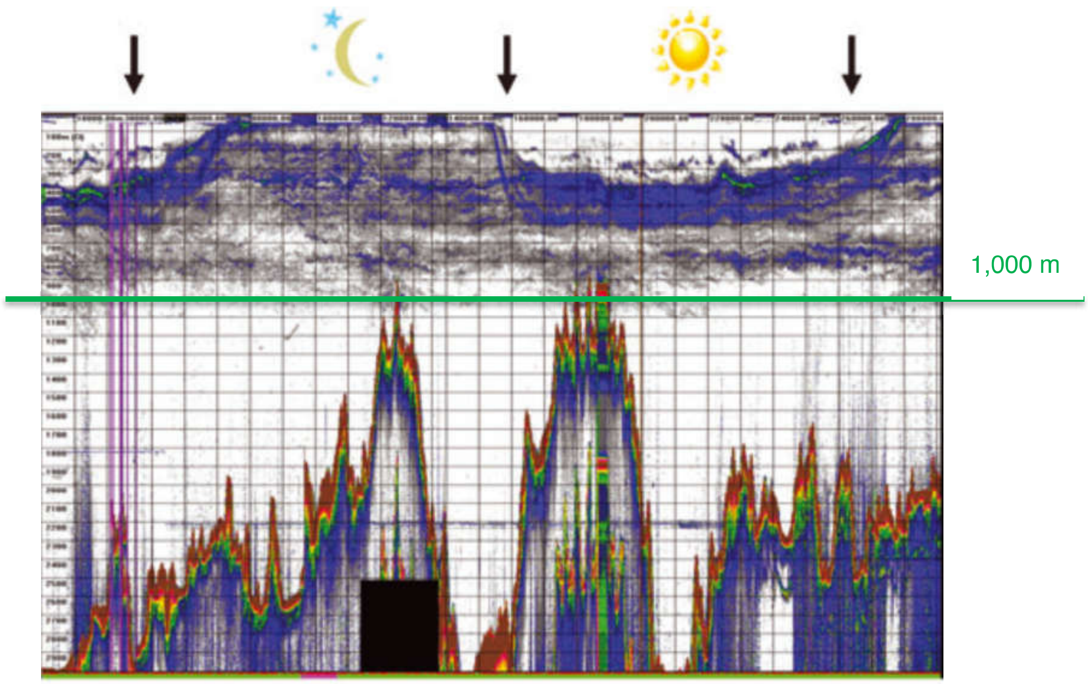
The following information and qualifications are presented to support the generation of this opinion:

- Review of oceanographic data collected at NORI-D, namely water samples, oceanographic profiles and ADCP records.
- Rapid review of research in the area of mesopelagic ecosystem processes. Timelines prohibit an exhaustive review.
- Knowledge and opinions of Dr Adrian Flynn who has a PhD in mesopelagic ecology and has published papers in this area.

2. The Mesopelagic Zone

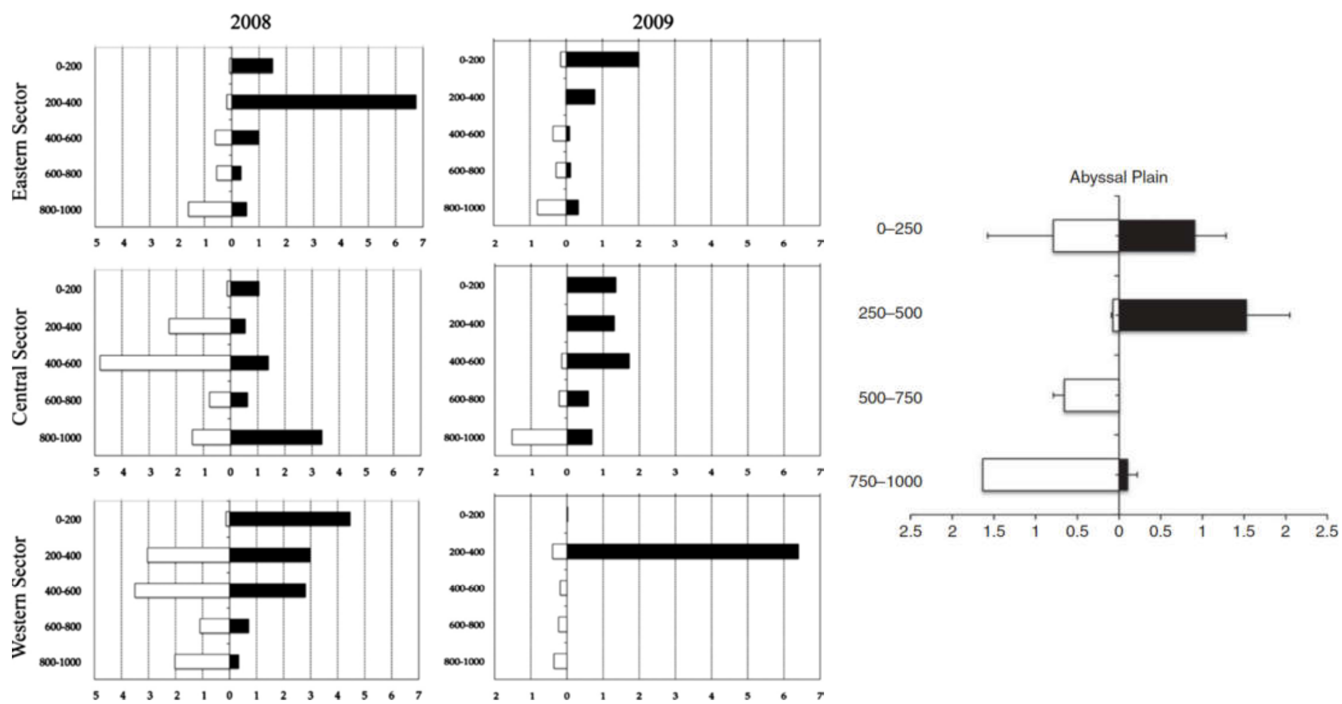
The mesopelagic zone is defined as a layer spanning 200–1000 m water depth. The definition is and not based on any particular biogeochemical limits or gradients. The 1000 m lower boundary is generally considered the maximum penetration of light (thus the term 'the twilight zone'), although this is obviously site-specific.

The mesopelagic zone is generally an area of high biomass when compared to deeper midwater layers. The mesopelagic zone is also generally an area of highest diel vertical migration activity. Diel vertical migration is the process whereby mesopelagic organisms residing in deeper layers of the mesopelagic zone and the mathypelagic zone during the day, ascend through the night to occupy shallow layers of the mesopelagic zone or into the epipelagic zone (0-200 m water depth) (Figure 1, Figure 2).



Source: Sutton 2013

Figure 1 Cross section transect across Mid-Atlantic Ridge showing midwater backscatter and seabed.



Sources: Flynn and Kloser (2012), Flynn and Williams (2012)

Figure 2 Day (white bars) and night (black bars) vertical distribution of micronekton biomass in the Tasman Sea (left) and Southern Ocean (right), illustrating diel vertical migration.

Diel vertical migration is a key ecological process (the biological pump) that connects photosynthetically derived production from the sunlit layers of the ocean to deeper, unlit layers and delivers particulate organic matter to deep strata and ultimately the seafloor.

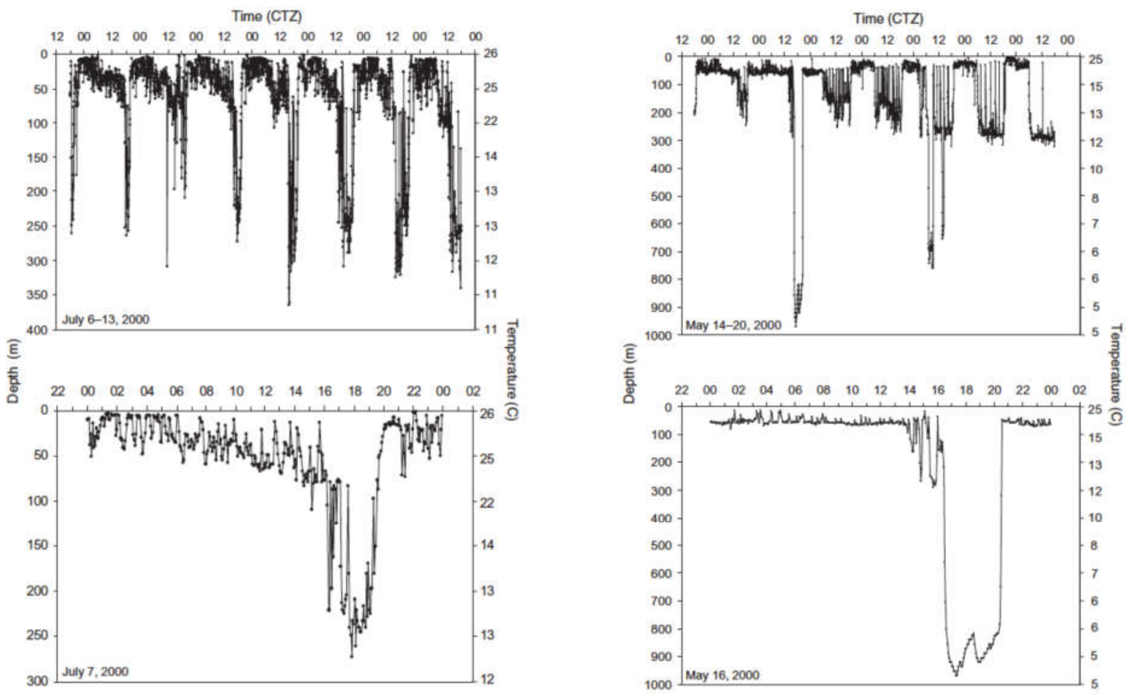
Organisms undertaking diel vertical migration include zooplankton of various sizes, but typically the macrozooplankton are most abundant and have the required motility to undergo the vertical movements, fishes, cephalopods, pelagic worms and other molluscs. These organisms migrate to graze on phytoplankton and zooplankton resources in the shallow layers or intercept migrating prey. Larger predatory species may also migrate from the bathypelagic zone (1,000-4,000 m) to intercept the migrating fauna in the mesopelagic zone.

The depth to which the migrating fauna reach at night is dictated by behaviour, energetics and niche selection. Generally, migrating fauna settle into into multi-species assemblages separated into vertical niches and specialise on a certain prey component which is often structured by size. Therefore, the vertically migrations consist of strongly migrating fauna that reach the epipelagic zone and other fauna migrate over shorter distances within the mesopelagic zone, and still other fauna that do not migrate.

Within the mesopelagic zone, there is oceanographic and physicochemical structure. Stratification, shearing layers, oxygen minima, clines and gradients exist. This physical and biochemical structure can influence biological distributions by providing 'trapping' of prey and therefore enhanced feeding habitat, by creating boundaries that are energetically expensive to cross and therefore represent 'ceilings' or 'floors' to distributions, or by providing dispersal pathways that may be actively sought to facilitate horizontal migrations.

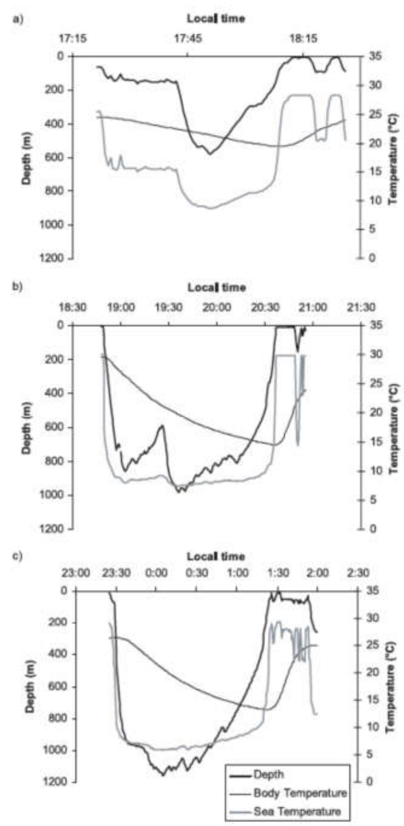
Epipelagic predators such as tunas, billfishes and cetaceans can dive into the mesopelagic zone to feed. While cetaceans can echolocate to find prey, deep-diving fishes are principally visual predators and therefore deep-dive mainly during the day. Indeed, some species are specialised deep-divers that feed in the mesopelagic zone (Figure 3, Figure 4). The diving behaviour of such predators is spatially variable and dependent on age-class, temperature and prey availability.

From a public perception point of view, it is my opinion that a discharge depth of 1,000 m will be interpreted as residing WITHIN the mesopelagic zone, a known highly productive layer of the water column which is the layer most closely linked to epipelagic foodwebs and fisheries, via the process of vertical migration. Indeed, it is my opinion that given the vocal opposition, this definition and categorisation of "the discharge in the mesopelagic zone" will likely outweigh any technical information provided below and any argument that could be mounted or measurements that could be provided around the relative biological activity at 1000 m.



Source: Schaeffer and Fuller 2002

Figure 3 Bigeye tuna dive profiles during 'shallow' foraging (left) and 'deep' foraging dives (right) in the eastern equatorial Pacific Ocean.



Source: Dagorn et al. 2006

Figure 4 Yellowfin tuna dive profiles in the western Indian Ocean (a) 578 m max., (b) 982 m max., (c) 1,160 m max.

3. The Lower Mesopelagic Boundary

At the base of the mesopelagic zone, nominally at 1000 m, there is a transitional area that interfaces with the bathypelagic zone. This so-called lower mesopelagic boundary is detectable as a region of high richness, abundance and biomass in the biological community, and is also indicated by physicochemical parameters such as nutrients, oxygen and silicate as proxies for productivity, consumption and biogeochemically important elements.

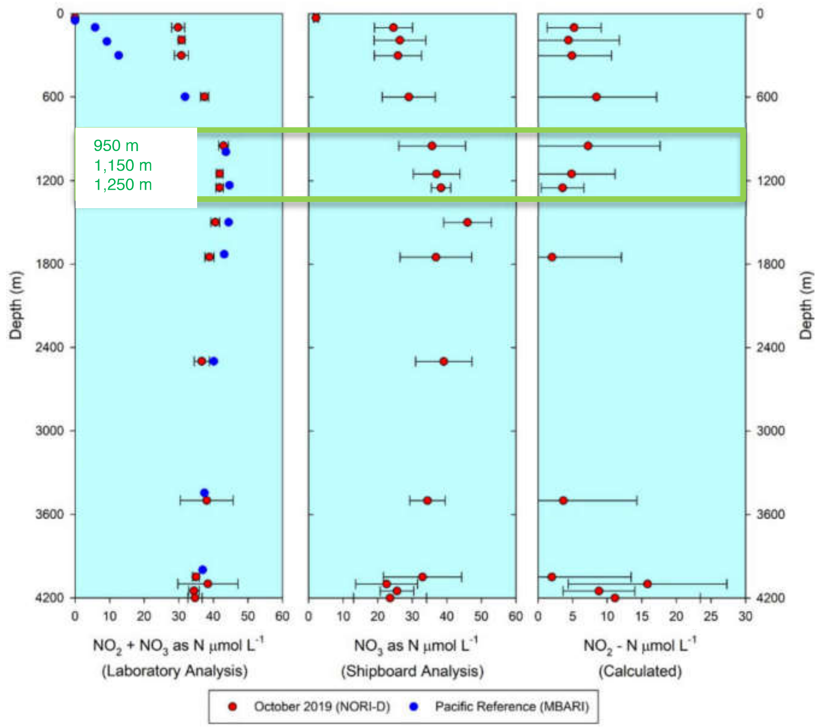
Ecologically relevant gradients in physicochemical parameters from the base of the mesopelagic zone and the bathypelagic zone are evident in data from NORI-D (Figure 5, Figure 6, Figure 7).

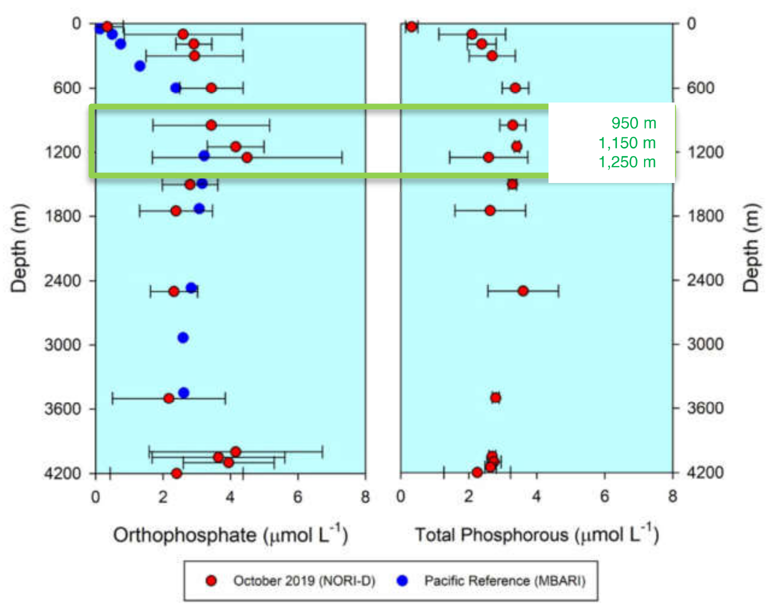
In a review by Sutton (2013), the following statement is made about the mesopelagic-bathypelagic interface:

> In the North Atlantic Ocean, investigations with an rectangular midwater trawl (RMT) 8 revealed a decline in fish biomass with depth below 1000m (Angel & Baker, 1982; Angel, 1989a), although recent studies with larger gear have reported bathypelagic fish biomass figures considerably higher than previously reported (Sutton et al., 2008; Fock & Ehrich, 2010; Cook et al., 2013). Depths around 1000 m often contain the species richness maxima of both the deep-pelagic and megabenthic faunas (Angel, 1993).

Stable isotopes analysis points to some demarcation in food sources around the mesopelagic-bathypelagic interface. Gloeckler et al. (2018) reported that a group of fauna clustered together had trophic affinities to large particles, while another group clustered together with affinities to small particles (Figure 8). This transition occurred around the 1,000-1,200 m depth and suggests that there is a shift in the trophic pool around this depth.

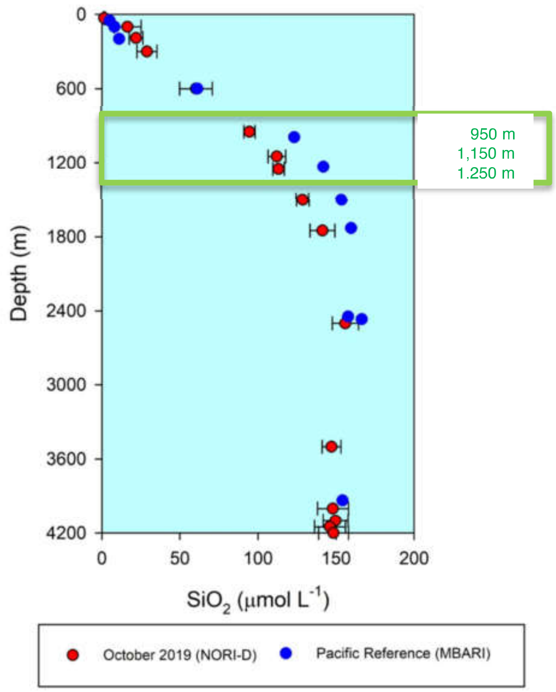
Meta-analysis of global respiration in the open ocean also points to a zone of enhanced biological activity at the mesopelagic-bathypelagic interface (Figure 9).





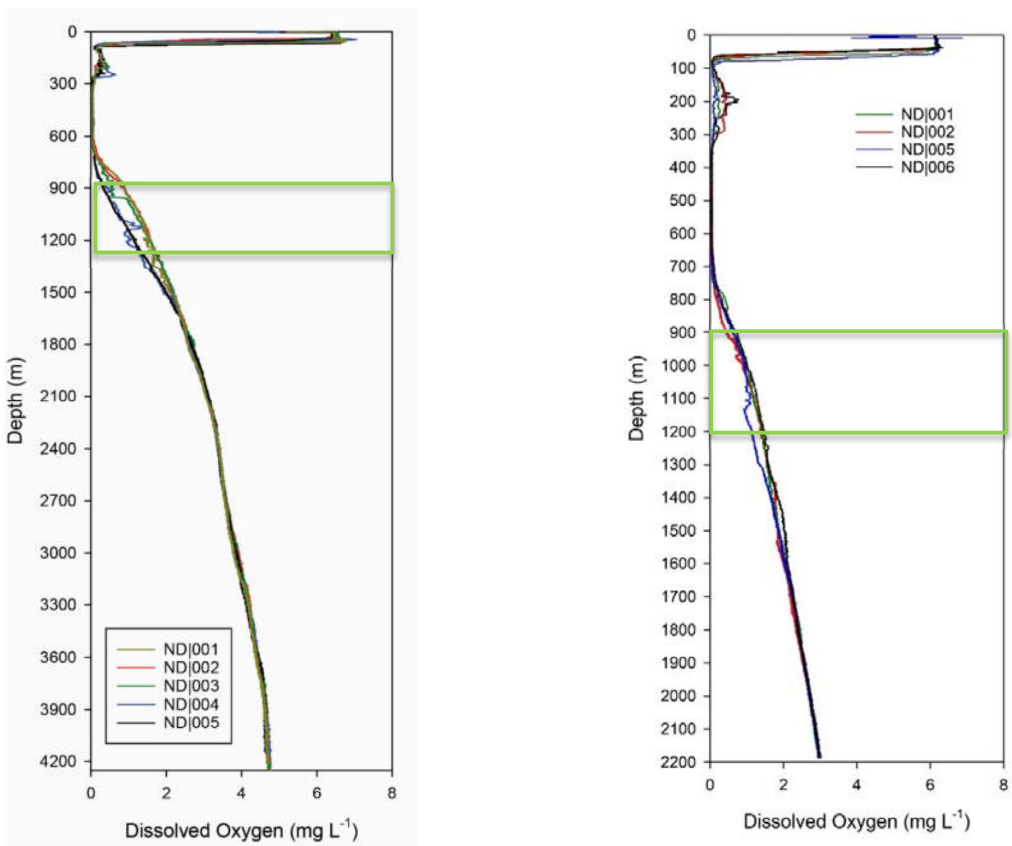
Source: CSA 2020a

Figure 5 Average (±SD) nitrogen, nitrate and calculated nitrite (top) and orthophosphate and total phosphorus concentrations (bottom) at NORI-D (October 2019). Green box denotes the mesopelagic-bathypelagic interface and green text lists the depths at which samples were taken.



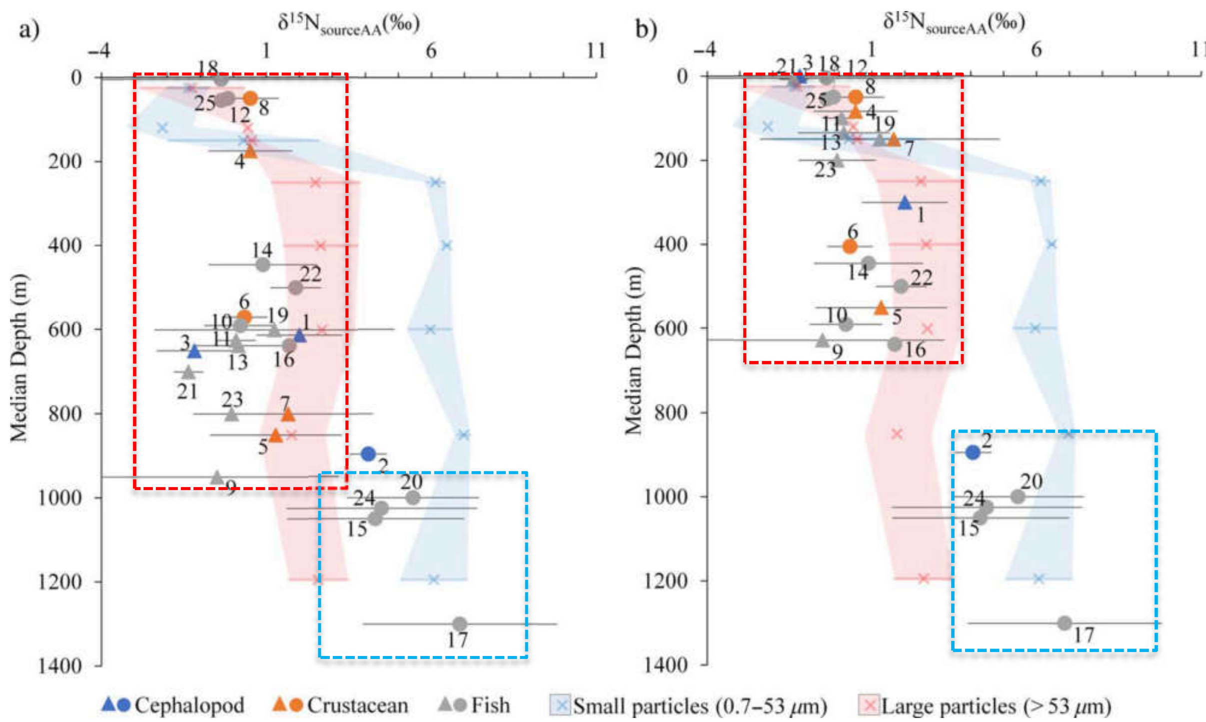
Source: CSA 2020a

Figure 6 Average (±SD) silicate concentrations at NORI-D (October 2019). Green box denotes the mesopelagic-bathypelagic interface and green text lists the depths at which samples were taken.



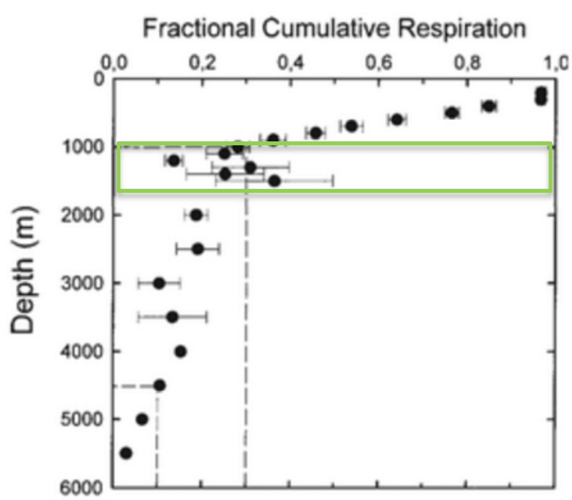
Source: CSA 2020a, b

Figure 7 Dissolved oxygen profile (mg L^{-1}) at NORI-D in October 2019 (left) and June 2020 (right). Green box denotes the mesopelagic-bathypelagic interface.



Source: Gloeckler et al. 2018, modified by A. Flynn.

Figure 8 Stable isotope values of fauna in relation to small and large particles during the day (a) and night (b), indicating the trophic associations in the mesopelagic zone are distinct from the bathypelagic zone and a transition in those two trophic pools occurring at the mesopelagic–bathypelagic interface ~1,000 to ~1,200 m. Red box = mesopelagic pool, blue box = a bathypelagic pool.



Source: Aristegui et al. 2005, modified by A. Flynn

Figure 9 Depth distribution of average cumulative respiration. Dotted lines represent depths at which 30% and 10% of total water column respiration occurs.

4. Conclusions and Recommendation

On the basis of this review, the conclusions are:

- If the discharge is placed at 1,000 m, there is likely to be a public perception that discharge is intentionally placed WITHIN the mesopelagic zone, a known productive zone of the open ocean with links to key ecosystem processes.
- At NORI-D, 1,000 m is within a zone of interface and gradients between the mesopelagic and bathypelagic zone. In other areas, the mesopelagic-bathypelagic interface has been shown to be biologically rich and a zone of transition from a mesopelagic fauna and trophic systems and a bathypelagic fauna and trophic systems.
- It is recommended that the depth of discharge is increased in order to avoid the definitional boundary of the mesopelagic zone, and the apparent mesopelagic-bathypelagic interface region.
- It is recommended that the discharge depth should be no shallower than 1,200 m.

5. References

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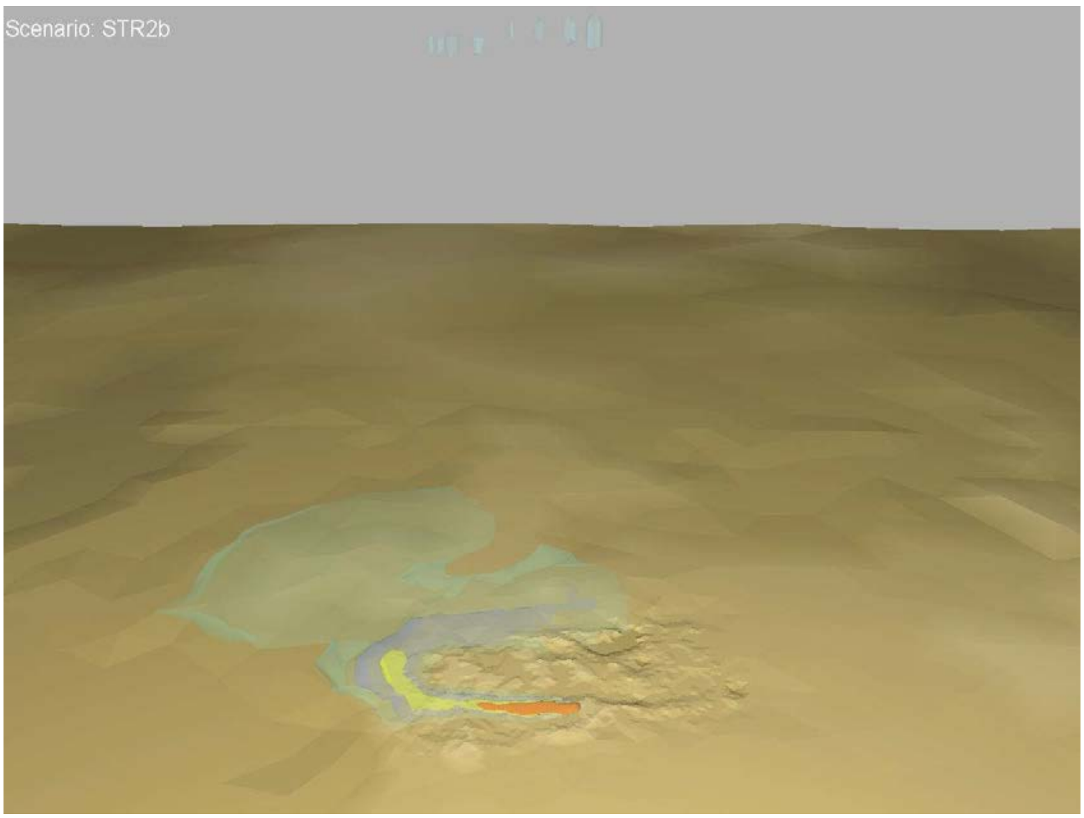
Dr Adrian Flynn

Appendix 2 – NORI-D Pilot Collector Test Sediment Plume Modelling (DHI, 2021)

NORI-D Pilot Collector Test Sediment Plume Modelling

Draft Report



The expert in WATER ENVIRONMENTS

April 2021

This report has been prepared under the DHI Business Management System
certified by Bureau Veritas to comply with ISO 9001 (Quality Management)

ISO 9001
Management System Certification
BUREAU VERITAS
Certification Denmark A/S

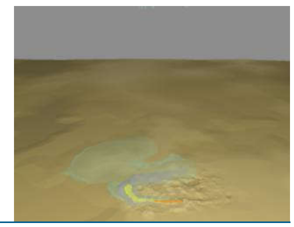
Approved by
Tom Foster President

NORI-D Pilot Collector Test Sediment Plume Modelling

Draft Report

Prepared for CSA Ocean Sciences Inc.

Represented by Bruce Pudney



Project manager	Josh Jon van Berkel
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Project number	41804716-01
Approval date	2021/04/29
Revision	6.0
Classification	Restricted

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1 Introduction

DHI Water & Environment, Inc. (DHI) has been commissioned by CSA Ocean Sciences Inc. (CSA) to carry out hydrodynamic and sediment plume modelling studies for the DeepGreen deep sea mining Block D concession area held by Nauru Ocean Resources Inc. (NORI) in the Clarion-Clipperton Zone (CCZ). The present report provides the results of the sediment plume modelling carried out for the nodule collector test scheduled for January 2022.

2 Modelling Methodology

The modeling focuses on the dispersion of sediments from the spill sources at the nodule collector and sediment wastewater discharge (also referred to as the mid-water column discharge). While the modelling approach allows a differentiation between the near-field (where the momentum and buoyancy of the discharge is controlling) and the far-field (where advection and dispersion is controlling, often referred to as the passive plume phase), sediment discharge volumes for the pilot test are relatively small. Consequently, only the far field processes are considered in the pilot collector test sediment plume assessment (i.e. the effects of momentum and buoyancy are assumed to affect less than one model computational cell (ca. 50m)).

2.1 Modelling Software

The numerical modeling carried out to assess the potential sediment plume impact involved a range of MIKE by DHI models that captured, reproduced and evaluated the deep ocean hydrodynamic processes and mid-water column and near-seabed sediment spill within the study area. This necessitated coupling between a hydrodynamic sediment transport model.

The model modules applied in this study are briefly described below:

- **MIKE 3 FM HD:** MIKE 3 FM HD is a 3-dimensional hydrodynamic model based on a flexible mesh approach that has been developed by DHI for applications within oceanographic, coastal and estuarine environments. The model is based on the numerical solution of the three-dimensional (3D) incompressible Reynolds averaged Navier-Stokes equations, subject to the assumptions of Boussinesq and of hydrostatic pressure. The spatial discretization of the equations is performed using a cell centered finite volume method. The horizontal discretization can combine triangular and quadrilateral elements, while the vertical discretization is based on a combined sigma-z discretization. Together with the inclusion of the Flather boundary conditions, the model is ideal for downscaling regional scale oceanographic models such as the HYbrid Coordinate Ocean Model (HYCOM) for high resolution applications. The regional scale resolution and bathymetry of the oceanographic models can be matched at the boundaries minimizing boundary error, then gradually imposing the higher resolution through the flexible mesh approach in the specific area of interest. MIKE 3 FM HD has been used to simulate the water levels, current, salinity and temperature in the area of interest over a typical January production period matching the likely seasonal processes anticipated during the pilot collector test, scheduled for January 2022 at the time of simulation.

- **MIKE 3 FM MT:** MIKE 21 FM MT is a 3-dimensional model for multi-fraction cohesive sediment transport that describes the processes of settling, erosion, transport and deposition of sediment under the influence of currents and waves. The model can be directly coupled with the hydrodynamic model to be able to include sediment plume density effects etc. in the hydrodynamics. The model includes routines for flocculation, hindered settling and fluid mud and can incorporate both cohesive and non-cohesive material in the same simulation. Overall, the MIKE 3 FM MT model calculates the resulting transport, dispersion, settling, deposition and re-suspension of sediments (cohesive and non-cohesive) brought into suspension by the pilot collector works.

2.2 Hydrodynamic Model Setup

2.2.1 Bathymetry, Mesh and Layers

The model bathymetry within the concession area has been established from the survey point cloud of depth soundings provided by DeepGreen as listed below:

- Multibeam Survey Data, 50m resolution

Outside the survey area bathymetry data is taken from the General Bathymetric Chart of the Oceans (GEBCO_2020) grid. The GEBCO_2020 Grid is the latest global bathymetric product released and developed through the Nippon Foundation-GEBCO Seabed 2030 Project. Agreement between the multibeam survey data and the GEBCO data at the boundary of the concession area is found to be good.

For the assessment of the pilot collector test, the developed mesh for the HD model of the NORI-D area has been cropped in size to focus on the pilot nodule extraction work area. This is scheduled to occur in NORI-D sub-Area 6 based on information provided by DeepGreen and Allseas. For the pilot collector test model design, a nominal 50m mesh resolution covering Area 6 has been found to provide a reasonable balance between resolution of bed features and the sediment plume against computational time. This resolution is decreased progressively towards the model boundaries, with a nominal mesh resolution of 2000m at the model boundary (approximately 30km from the work area).

The resulting mesh, after completion of the various development sensitivity tests, is shown in Figure 2.1. The full model domain bathymetry is shown in Figure 2.2, with detail of the Area 6 pilot collector test area, where the sediment plume is anticipated, shown in Figure 2.3.

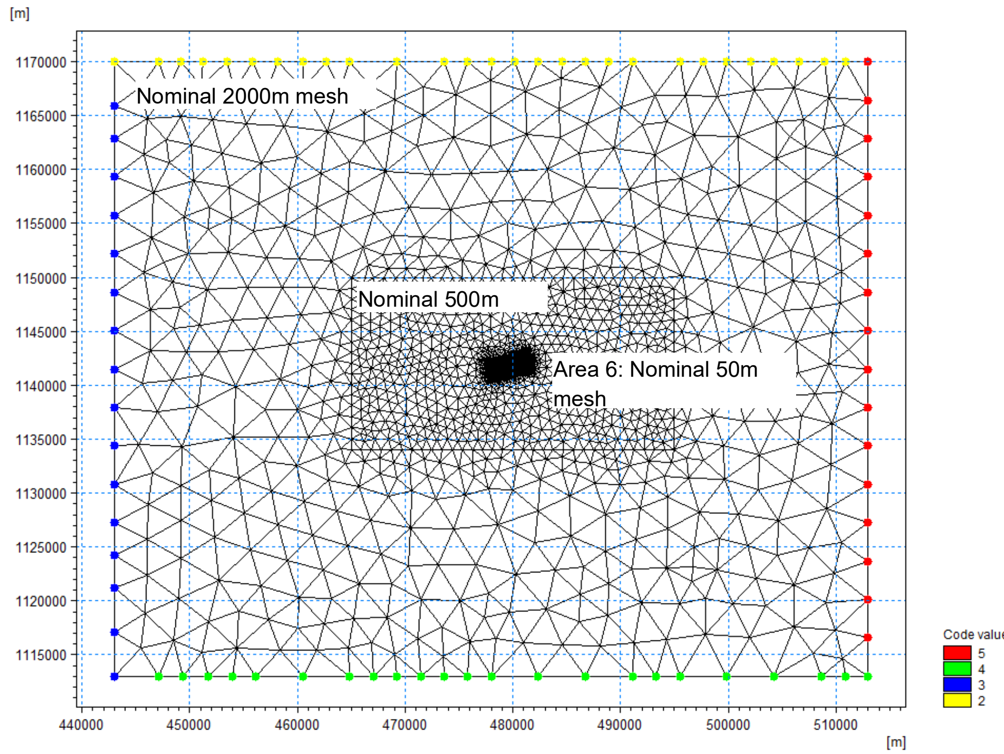

Figure 2.1 Collector test model mesh

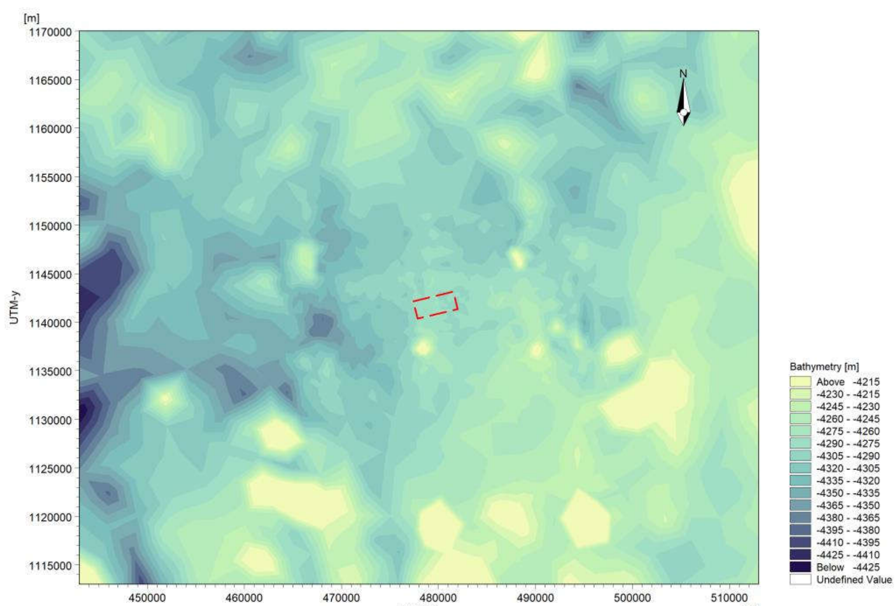

Figure 2.2 NORI-D Pilot collector test sediment plume model bathymetry with the pilot collector test area (Area 6) highlighted

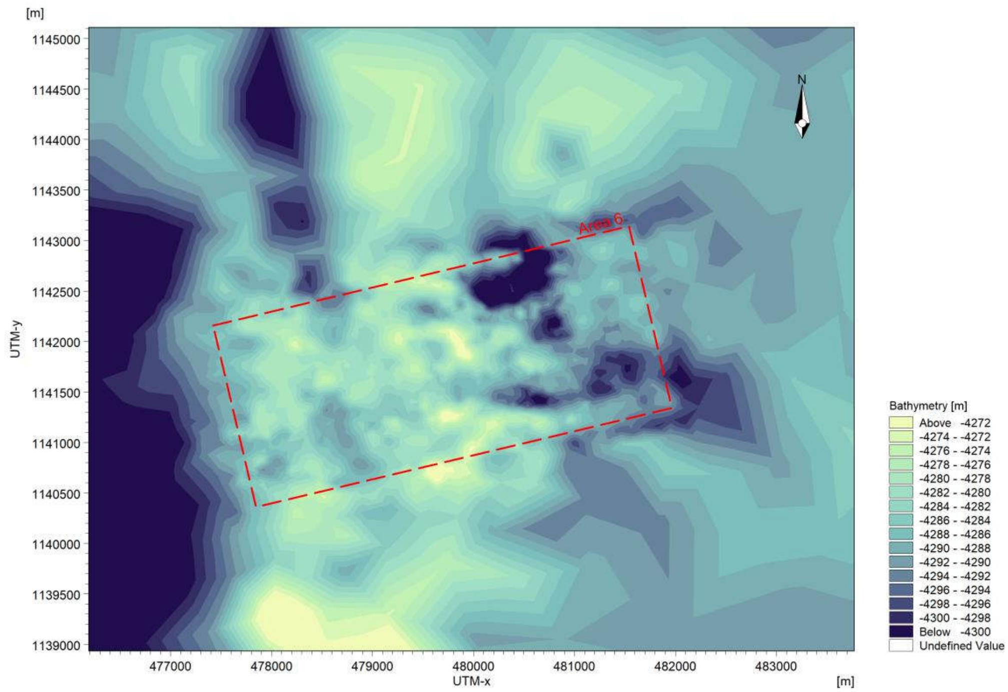

Figure 2.3 Detail of the Area 6 pilot collector test sediment plume model bathymetry

Testing of various vertical layer schemes has been undertaken during the development of the pilot collector test sediment plume model. Focus has been placed on achieving a near-bed layer and mid-water column resolution that will provide adequate resolution of the sediment plume.

The vertical layer thickness in MIKE 3 FM can be defined either as a fraction of the water depth (adaptive layering, termed σ layers) and/or at fixed water depths (z layer). For computational efficiency, a σ layer arrangement appears appealing. However, due to the deep ocean depths of NORI-D and the relatively large local variations in depth in Area 6, a combined σ-z grid was found to provide superior performance in terms of salinity, temperature and near-bottom currents. Consequently, as the ultimate purpose of the modelling is to resolve the sediment plume transport and dispersion near the seabed and near the mid-water column discharge, a combination of an adaptive layering scheme and fixed water depths has been adopted for the pilot collector model as defined in Table 2.1 and Table 2.2. Using this mixed σ-z distribution, the model includes 51 layers over the water depth, see Figure 2.4.

Table 2.1 Preliminary model vertical sigma layering from 0 – 100 m water depth

Adaptive Layer elevation as % of water depth (height below water surface)	Nominal Layer height (m) below water surface for cell center with 100 m water depth	Nominal layer thickness (m) for cell with 100 m water depth
50%	50	50
50%	100	50

Table 2.2 Preliminary z-level vertical layers from 100-4440 m water depth

Nominal Layer height (m) above seabed for cell center with 4642 m water depth	Nominal layer thickness (m) for cell with 4642 m water depth
400	300
600	200
800	200
900	100
950	50
1000	50
1050	50
1100	50
1150	50
1200	50
1250	50
1300	50
1350	50
1400	50
1450	50
1550	100
1650	100
1750	100
1850	100

Nominal Layer height (m) above seabed for cell center with 4642 m water depth	Nominal layer thickness (m) for cell with 4642 m water depth
2050	100
2250	200
2450	200
2650	200
2850	200
3050	200
3250	200
3450	200
3650	200
3850	200
4050	200
4150	100
4200	50
4230	30
4250	20
4260	10
4264	4
4268	4
4272	4
4276	4
4280	4
4284	4
4288	4
4292	4
4296	4

Nominal Layer height (m) above seabed for cell center with 4642 m water depth	Nominal layer thickness (m) for cell with 4642 m water depth
4300	4
4310	10
4330	20
4360	30
4440	80

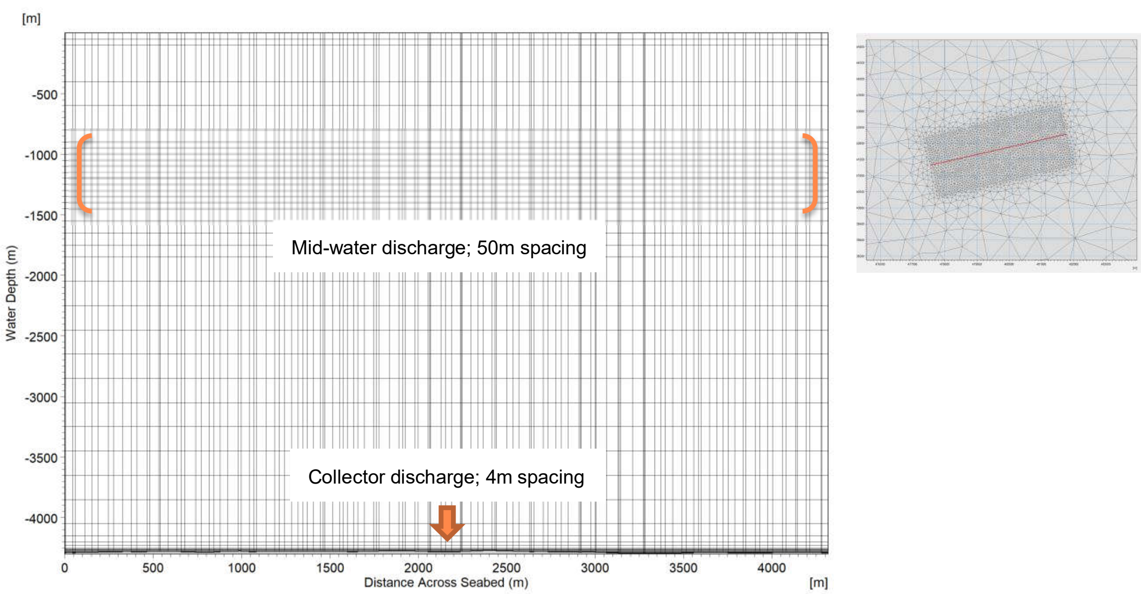

Figure 2.4 Longitudinal slice through Area 6 vertical resolution increases around the mid-water column discharge (-1000m) and near the seabed.

Due to the suspended sediment modelling requirements in the MT module, the hydrodynamic timestep has to be greatly reduced from that required for hydrodynamic model stability (i.e. higher resolution) to 300s. After much sensitivity testing, the duration of the model production period for each collector test scenario was set at 11 days. This proved adequate for model warm-up and coverage of the collector test operation and subsequent transport, dispersion and settling of the plume to a level where all concentrations had reduced to a level of at least an order of magnitude below anticipated background level.

2.2.2 Model Boundary Conditions

The hydrodynamic model utilizes boundary conditions from the HYCOM oceanographic model (HYCOM 2021). Validation of the suitability of the HYCOM model for provision of boundary conditions to the NORI-D model area has been undertaken against measurements in the central Pacific collected as part of the Global Tropical Moored Buoy array maintained by the National Oceanographic and Atmospheric Administration (NOAA 2021) and against satellite derived current measurements maintained by the European Union Copernicus Marine Science program (Copernicus 2021). Example of HYCOM performance against the NOAA measurement in the general area of NORI-D is provided in Figure 2.5 and against the Copernicus measurements extracted at the NORI-D long mooring location in Figure 2.6. Overall, the comparison between HYCOM and the available regional current monitoring data is found to be adequate from a model boundary generation perspective.

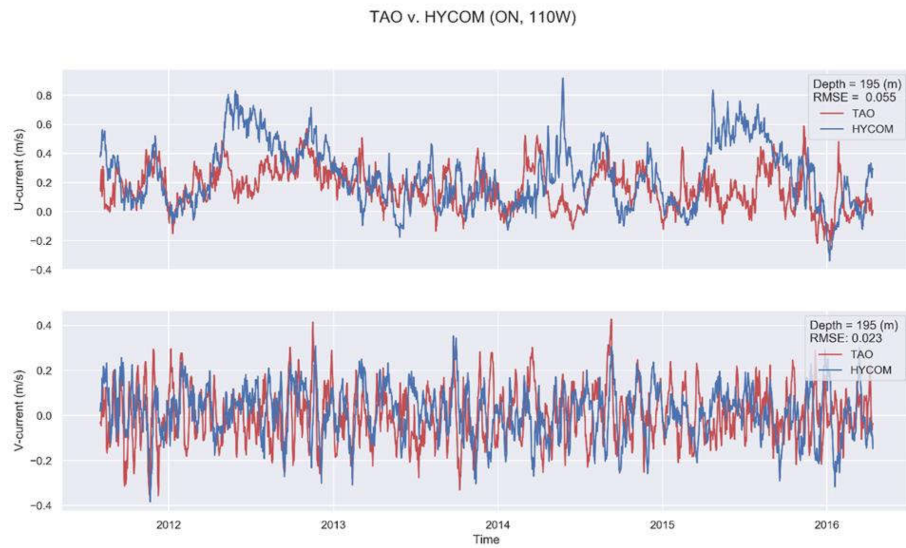

Figure 2.5 Example of HYCOM performance against NOAA Tropical Ocean Atmosphere (TAO) buoy measurements (NOAA 2021) at 0ºN, 110ºW

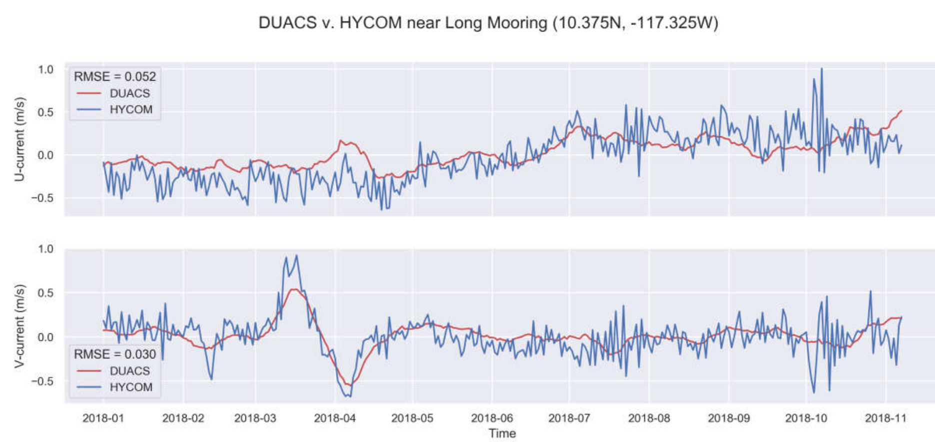

Figure 2.6 Example of HYCOM performance against Data Unification and Altimeter Combination System (DUACS) measurements (Copernicus 2021) near NORI-D long mooring (10.375ºN, 117.325ºW). Note satellite measurements are daily and as such do not capture shorter term variability

2.2.3 Hydrodynamic Model Validation

Since 2019, DHI has progressively developed the hydrodynamic (HD) model for the NORI-D area. At the time of the present report, model validation has been performed against the first set of current measurements from the NORI-D area (CSA 2020). A summary of the near-bed current data is provided in Figure 2.7, showing a dominant north-north-west / south-east flow direction for the approximately 8 months of data available at the time of writing.

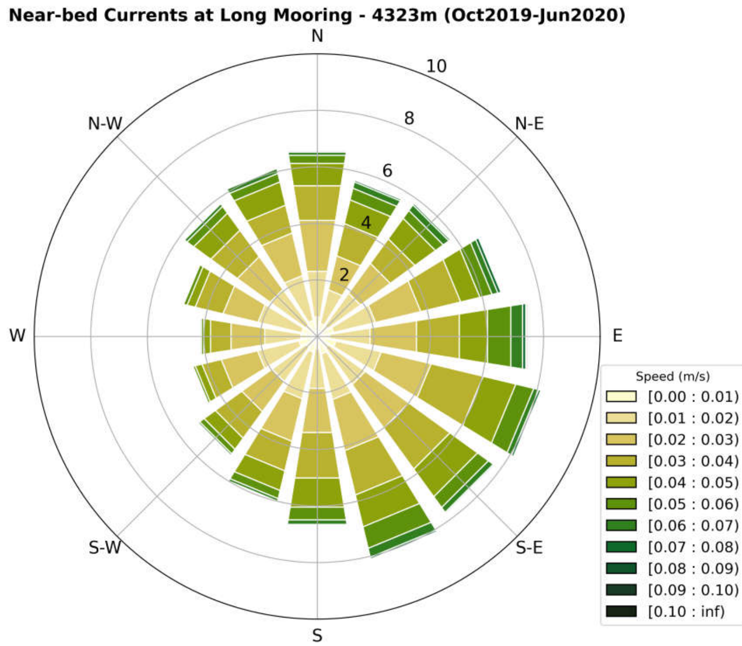

Figure 2.7 Summary of measured near bed current data from NORI-D long mooring (current flowing to) 14 October 2019 to 26 June 2020

Example, model performance against a sub-set of this site-specific measurement data is provided in Figure 2.8. This shows generally good performance in terms of modelled vs. measured current speed through the water column. The hydrodynamic model will continue to be progressively improved as more data becomes available (from subsequent field campaigns). However, based on the validation results presented in Figure 2.8 the hydrodynamic model is considered fit for purpose for the assessment of the relatively small (from a sediment spill perspective) pilot collector test.

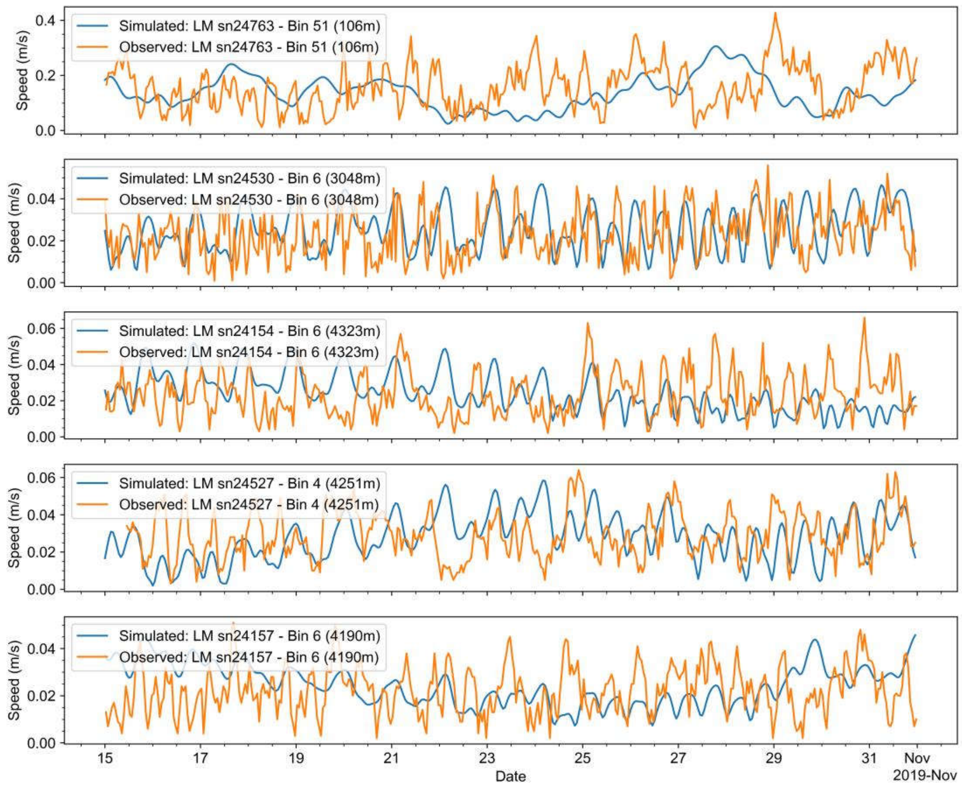

Figure 2.8 Validation of the preliminary HD model against the measured ADCP data

2.3 Suspended Plume Modelling Setup

2.3.1 Sediment Settling Characteristics

The sediment settling characteristics of the seabed material, that will be introduced into the water column as a result of the pilot collector operation, have been determined based on detailed laboratory tests of seabed sediment from the NORI-D concession area undertaken by iSeaMC (iSEAMC 2020). From a modelling perspective, the results of these laboratory experiments can be summarised by a set of sediment settling velocities as a function of sediment concentration. Two test sequences were carried out, one with a starting concentration of 1g/l and a second with a starting concentration of 10g/l. Results in terms of settling velocities as a function of concentration, provided by ISeaMC, are summarised in Table 2.3 and Table 2.4.

Table 2.3 Bottom sediment settling characteristics (particle size and settling rate) as a function of ambient concentration (iSeaMC 2020). Starting concentration 1g/l

Starting concentration 1g/l	Time	T=10 min.	T=30 min.	T=60 min.	T=120 min.	T=180 min.	T=240 min.	T= 24 hr.
Characteristic	Particle Concentration [g/l]	0.911	0.427	0.14	0.072	0.053	0.046	0.008
d_{25}	µm	294	465	279	199	161	154	282
d_{50}		448	681	386	278	228	218	326
d_{75}		671	933	506	370	313	289	375
$W_{s\,25}$	m/d	81.8	125.9	78.7	63.9	57.8	56.7	79.3
$W_{s\,50}$		120.7	209.2	103.4	78.5	68.9	67.2	88.8
$W_{s\,75}$		204.6	350.9	139.1	99.3	85.9	80.8	100.6

Table 2.4 Bottom sediment settling characteristics (particle size and settling rate) as a function of ambient concentration (iSeaMC 2020). Starting concentration 10g/l

Starting concentration 10g/l	Time	T=10 min.	T=30 min.	T=60 min.	T=120 min.	T=180 min.	T=240 min.	T= 24 hr.
Characteristic	Particle Concentration [g/l]	9.368	6.559	0.767	0.079	0.058	0.052	0.007
d_{25}	µm	863	1292	430	213	157	122	318
d_{50}		1378	1902	641	296	206	161	371
d_{75}		2085	2395	830	412	268	208	437
$W_{s\,25}$	m/d	204.5	377.8	99.9	68.2	61.7	58	82.2
$W_{s\,50}$		420.6	704.6	142.9	79	67.4	62.2	90.2
$W_{s\,75}$		797.5	929	194.2	96.8	75.2	67.6	101.1

As intermediate concentrations are established by letting the tests continue for a period of time, with the lower concentrations being achieved as sediment falls out of suspension, the assumption must be made that the material remaining in suspension remains representative of the starting material grading distribution. This is a reasonable assumption given the fact that the tests are undertaken at a constant rate of shear. Further, the derived settling characteristics also demonstrate the expected flocculation characteristics across the range of test concentrations. This would not be the case if there was a significant change in the underlying non-flocculated sediment characteristics. Consequently, while it is recognised that additional testing of intermediate starting concentrations would be beneficial to confirm the validity of the underlying assumption of no change in base sediment characteristics, all indications are that it is an appropriate assumption for the assessment of the sediment plume characteristics resulting from the pilot collector test program.

The sediment settling velocity formulation in MIKE 3 FM MT divides the concentration regime into three zones as shown in Figure 2.9. For the purpose of the pilot collector test sediment plume model, the assumption is made that the concentration in the passive plume will not exceed the passive plume hindered settling limit, which is expected to be in the order of 10g/l.

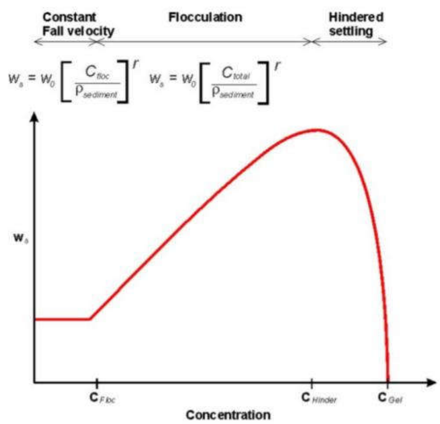

Figure 2.9 Sediment settling velocity formulation in MIKE 3 MT (outside the hinder settling regime)

Based on the iSeaMC laboratory data, flocculation is assumed not to occur at concentrations below 0.03g/l (30mg/l).

Between 0.03g/l and 10g/l flocculation is assumed to occur as a function of the total concentration of floc generating material. The flocculation formulation used in MIKE3 MT is shown in Figure 2.9. For a known sediment solid density, curve fitting is used to determine W_0 (the setting velocity coefficient) and r (the settling velocity power). The resulting settling velocity coefficients and settling velocity powers for the three sediment fractions identified by iSeaMC are documented in Table 2.5, calculated for a solid density of 2400kg/m^3 based on communication from iSeaMC.

Table 2.5 Flocculation parameters determined from the laboratory results presented in Table 2.3 and Table 2.4

Sediment Fraction	Parameter	Based on solid density of 2400kg/m^3
D_{25}	W_o	0.02851
	r	0.35
D_{50}	Wo	0.14277
	r	0.49
D_{75}	Wo	0.20221
	r	0.5

The resulting comparison between model and measured settling velocity for the three sediment fractions is shown in Figure 2.10. Overall, it should be stressed that this is a very high level of agreement between measured and modelled setting velocity. This is only possible due to the high-quality settling velocity measurements provided by iSeaMC.

The three sediment factions are introduced into the plume model with the working assumption for the pilot collector test assessment of equal distribution by mass in the three settling velocity fractions.

These data were introduced into the model with the following concentration limits:

Table 2.6 Other key settling parameters

Parameter	**Value**	**Unit**
Lower limit concentration for hindered settling	10,000	mg/l
Lower limit concentration for flocculation	30	mg/l

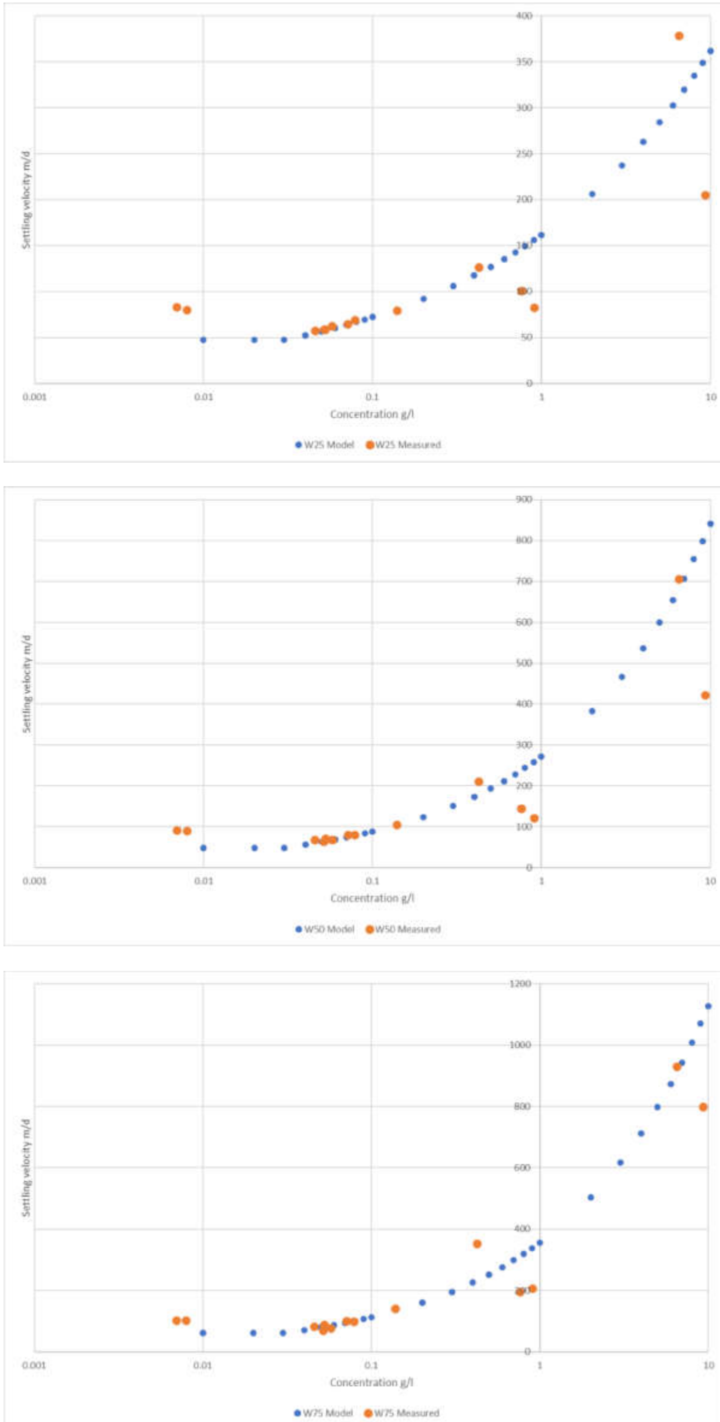

Figure 2.10 MIKE 3 MT sediment settling velocity as a function of concentration compared to iSeaMC measurements for the 3 sediment fractions identified by the laboratory experiments

In addition to the bed sediment, residual nodule material was included in the model with the following key settling characteristics

Table 2.7 Modelled residual nodule sediment settling characteristics

Fraction	Mean Grain Size, d (mm)	Settling Velocity, Ws (m/s)
Residual Nodule (D75)	0.8	0.102
Residual Nodule (D25)	6	5.735

2.3.2 Sediment Deposition and Resuspension Characteristics

The sediment deposition and resuspension characteristics are also important model parameters. Key parameters are presented in Table 2.8.

Table 2.8 Modelled sediment deposition and resuspension characteristics

Parameter	Value
Critical Shear Stress for Deposition	0.07N/m^2 (DHI 2017)
Deposition Density	180kg/m^3 (DHI 2017)
Critical Shear Stress for re-suspension	0.1N/m^2 (iSeaMC 2020)

Short term measurements of blanketing (iSeaMC 2020) indicate an initial deposition density in the order of 100kg/m^3. This is typical for freshly deposited fine material (DHI 2017). However, this will tend to consolidate with time and a longer-term deposition density in the order of 180kg/m^3 is considered more appropriate (DHI 2017) for quantification of the net sedimentation at the end of the pilot collector test program. This difference between initial and longer-term deposition density should be taken into account in the interpretation of the sedimentation results, in that, initial deposition thicknesses may be up to a factor of 2 higher than those presented, dropping to the presented figures over a period of weeks/months after the completion of the pilot collector test program as a result of consolidation. Further, it is noted that data from iSeaMC indicates considerable micro scale variability in sedimentation thickness as a result of the presence of the nodules. This should be expected to (at the micro scale) increase sedimentation thickness by between 30% and 100% in the depressions between nodules compared to the area average (iSeaMC 2020).

The critical shear stress for re-suspension is based on the results of re-suspension laboratory experiments carried out by iSeaMC in the presence of nodules (iSeaMC 2020) converted from limiting current speed to bottom shear stress.

2.3.3 Pilot Collector Test Discharge Characteristics

The pilot collector scenario plan has been established based on review of information provided from DeepGreen and Allseas. At the time of simulation the pilot collector test is scheduled for January 2022. Hydrodynamic forcing for the sediment plume model simulation is thus selected from a typical January period, with January 2017 being selected as typical.

Mid-Water Column Return Flow

The discharge is set at 1000m below surface based upon communication from Allseas and DeepGreen. Table 2.8 provides a summary of the key mid-water column discharge characteristics for the base pilot test operation. These data are scaled by the production for each scenario.

Table 2.9 Mid-water column discharge characteristics

Parameter	Value
Residual Nodule Sediment Load	1.17kg/s (0.0006 m^3/s)
Residual seabed sediment load	1.17kg/s (0.0005 m^3/s)
Water Discharge	0.097m^3/s (99/51kg/s)
Total Discharge including sediment	0.0981m^3/s
Discharge Temperature	7.5^{o}C
Discharge Salinity	34.67PSU
Discharge Configuration	Single 0.2m ø
Discharge velocity	3.12m/s
Discharge orientation	Vertically down
Discharge Depth	1000m
Mid-water column discharge offset	330m in advance of collector.
Riser movement	Same speed as collector

Collector Discharge Port Information

Key discharge characteristics for the pilot collector discharge have been provided by Allseas and DeepGreen. Sediment and water discharge characteristics are provided for the base pilot collector operation in Table 2.9. These data are scaled by the production for each scenario.

Table 2.10 Pilot collector discharge characteristics

Parameter	Value
Discharge Port Vertical Orientation	0°
Number of nozzles	4
Height above seabed	4m
Discharge port velocity	0.7m/s
Discharge port area	1m^2
Residual nodule sediment Load	Base 0.38kg/s (0.0002m^3/s)
Residual seabed sediment load	Base 16.72kg/s (0.007m^3/s)
Water Discharge	Base 2.186m^3/s (2241kg/s)
Total Discharge including sediment	Base 2.1932m^3/s
Discharge Temperature	Ambient at bed
Discharge Salinity	Ambient at bed
Collector speed	Varies depending on scenario
Collector track	Varies depending on scenario
Spill from tracks and track cleaning system	Not included for collector test sediment plume assessment as no data on spill rates, but expected to be small
Spill from collector head	Disturbance allowance of 2% of fine sediment flux = 0.02 * 17.10 kg/s = 0.342kg/s released at seabed with no discharge velocity. This is in line with data from hydraulic suction dredging techniques.

2.3.4 Pilot Collector Test Operations

System Test Runs (STR) are the only portion of the pilot test program put forward by Allseas that will generate any significant volume of sediment spill, with five (5) cases identified as dominating. Table 2.10 to Table 2.14 summarize the key data relevant from the sediment plume modelling for these 5 sediment plume generating cases.

Table 2.11 STR1b

Parameter	Value
Duration on seabed	26hrs
Run length	12.4km (4x3.1km run lines)
Average harvester speed	0.14m/s
Turn Distance	377m (4 turns)
Lane spacing	50m
Run duration (at 0.14m/s)	Production 24.6hrs
	Turning 0.75hrs
Delays	26 - 24.6-0.75 = 0.65hrs insert at turning
Net turning and delay time per turn (no production)	0.35hrs/turn
Production rate	686.9T in 12.4km = 55.3T/km
Mid-Water discharge	Present

Table 2.12 STR2a

Parameter	Value
Duration on seabed	9hrs
Run length	9.3km (3x3.1km run lines)
Average Harvester Speed	0.3m/s
Turn Distance	377m (2 turns)?
Run duration (at 0.3m/s)	Production 8.6hrs
	Turning 0.35hrs
Lane spacing	38m
Delay	9.0-8.6-0.35= 0.05hrs insert at turning
Net turning and delay time per turn (no production)	0.2hours
Production rate	750T in 9.3km = 80.6T/km
Mid-Water discharge	Present

Table 2.13 STR 2b

Parameter	Value
Duration on seabed	21hrs
Run length	22.32km (Contours)
Average Harvester Speed	0.3m/s
Turn Distance	Radius 20-200m (Production does not stop)
Run duration (at 0.3m/s)	Production 20.6hrs
	Turning N/A (Production does not stop)
Lane spacing	N/A
Delay	N/A (ignoring the 0.4hr discrepancy)
Production rate	1780T in 22.3km = 79.75T/km
Mid-Water discharge	Present

Table 2.14 STR 3a

Parameter	Value
Duration on seabed	4.5hrs
Run length	6.2km (2x3.1km run lines)
Average harvester speed	0.4m/s (Average of 2 lanes)
Turn Distance	188m (1 turn)
Lane spacing	10m
Run duration (at 0.4m/s)	Production 4.3hrs
	Turning 0.1hrs
Delays	4.5 - 4.3-0.1 = 0.1hrs insert at turning
Net turning and delay time per turn (no production)	0.2hrs/turn
Production rate	515T in 6.2km = 83.0T/km
Mid-Water discharge	Present

Table 2.15 STR 3b

Parameter	Value
Duration on seabed	8hrs
Run length	6.2km (2x3.1km run lines) but only mining on lane 2
Average harvester speed	0.25m/s (Average of 2 lanes)
Turn Distance	188m (1 turn)
Lane spacing	50m
Run duration (at 0.25m/s)	Production 3.4hrs
	Turning. N/A (as only one production pass)
Delays	Not relevant (as only one production pass)
Net turning and delay time per turn (no production)	Not relevant (as only one production pass)
Production rate	283.3T in 3.1km = 91.4T/km
Mid-Water discharge	Present

2.3.5 Pilot Collector Tracks

The pilot nodule extraction operations have been strategically placed within an Area 6 in a manner that avoids the locations with the largest elevation variance, i.e. the Eastern sector of Area 6. The nodule collector tracks for each scenario follow the Allseas execution plan. Run length and the speed at which the nodule collector would travel and production rate follows the parameters listed in Section 2.3.4. The nodule collector track for each operational scenario can be viewed in Figure 2.11 to Figure 2.15. Where, each blue point represents the location of the nodule collector each minute. After one pass (3.1 km) has been completed (excluding scenario STR2b), the nodule collector makes a turn and begins the next pass 50m south of its last location. The turning is not simulated in the model as it does not produce significant spill of sediment; however, the time delay for each turning event is considered before the start of the next pass.

It is important to note, that the mid-water column discharge occurring at 1000m below the surface follows the same track as the nodule collector. However, the assumption is made that, rather than moving constantly at the speed of the collector, the surface vessel (and thereby the mid-water column discharge) moves in 600m steps, moving from 300m behind to 300m in front of the collector with each step.

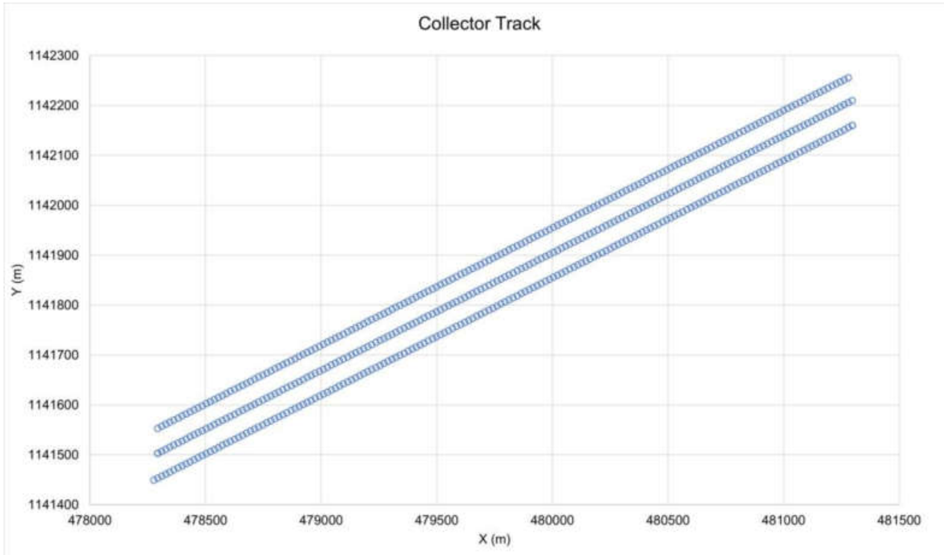

Figure 2.11 Scenario STR2a: Nodule collector track

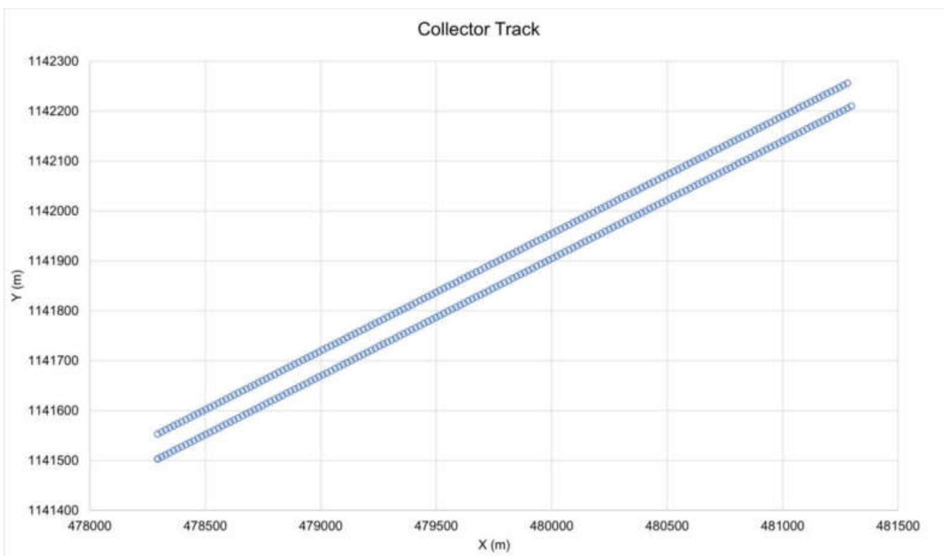

Figure 2.12 Scenario STR3a: Nodule collector track

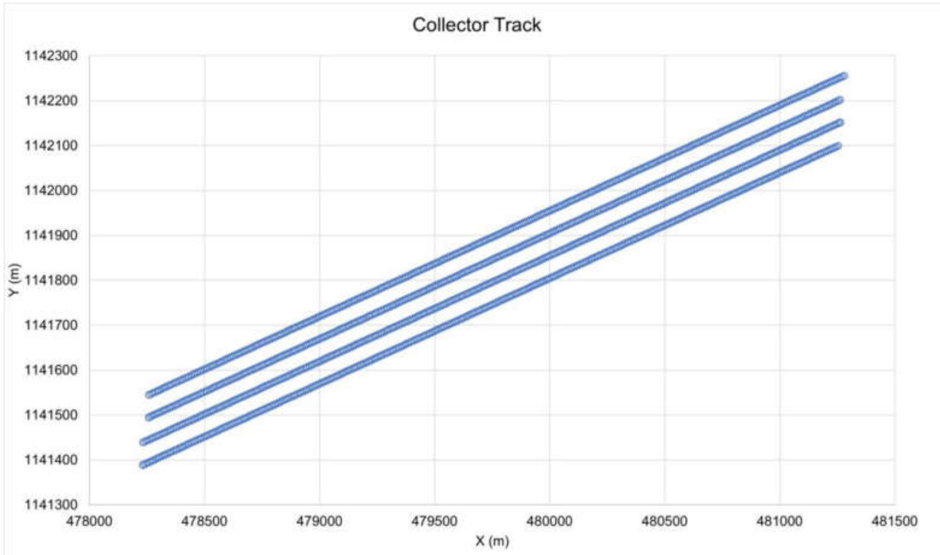

Figure 2.13 Scenario STR1b: Nodule collector track

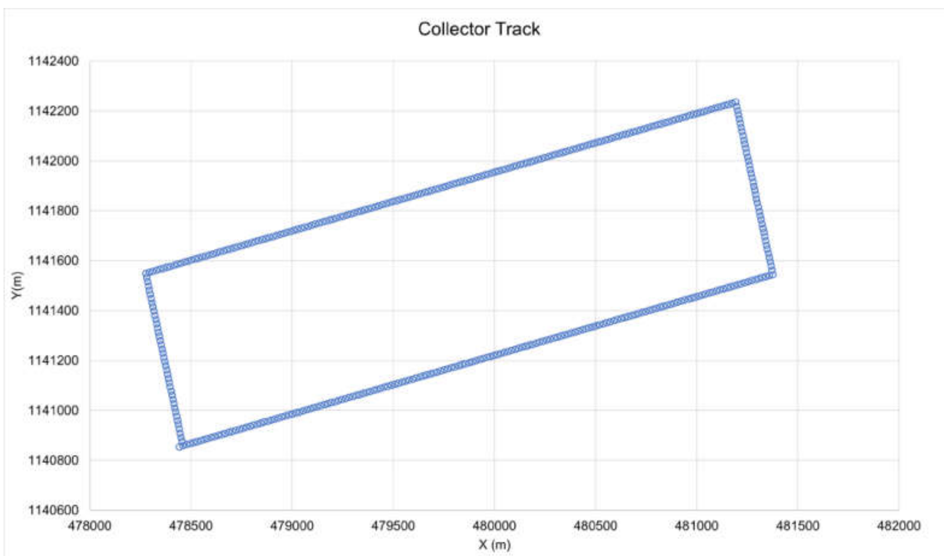

Figure 2.14 Scenario STR2b: Nodule collector track

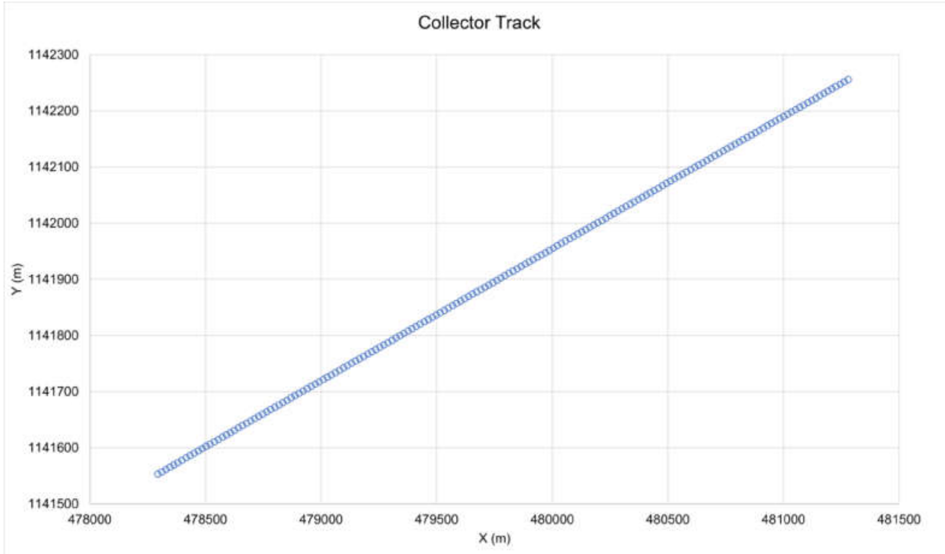

Figure 2.15 Scenario STR3b: Nodule collector track

3 Pilot Collector Test Sediment Plume Results

The sediment plume model results are presented in terms of incremental (above background) sedimentation and incremental (above background) Total Suspended Sediment (TSS) concentration, rather than absolute sedimentation and suspended sediment concentration. This is considered normal practice for sediment plume modelling (e.g. PIANC 2010, Marnane et al. 2017) for cases where:

- The background sedimentation and suspended sediment concentration varies weakly in space and time. In these cases it can be assumed that the environmental receptors are adapted to this weakly varying background and will thus respond to incremental stress above this background.
- Background concentrations are sufficiently low as to not influence the settling properties of the incremental material brought into suspension by the activities

Adequate field data to fully define background concentrations in the NORI-D area will only be available after ongoing filed campaigns are complete. However, it is considered a reasonable assumption that, due to the slowly varying current conditions in the area and deep oceanic nature of the environment, these two fundamental assumptions supporting the use of an incremental rather than absolute approach to the sediment plume modelling, are valid.

In assuming the validity of these assumptions, absolute concentration can be calculated from the presented model results by adding the spatially and temporally averaged background concentration to the incremental concentrations determined from the sediment plume model.

Results are presented for the five individual scenarios in terms of incremental sedimentation and incremental TSS concentration in the following sub-sections, with the cumulative effect of the pilot collector test operation presented in Section 4.

The incremental sedimentation is expressed in mm based upon an assumed medium term deposition density of 180kg/m^3 (See Section 2.3.2 for more details on deposition density).

In order to take into account both the magnitude and duration of the incremental TSS, the incremental TSS is expressed as the percentage exceedance of 0.1mg/l, 1mg/l, 5mg/l and 10mg/l above background concentration. These limits have been provided by DeepGreen.

Exceedance is calculated according to the following example:

- A concentation of 2mg/l present for 2hrs over a 10hr analysis period would result in an exceedance of 0.1mg/l of 20%, 1mg/l of 20% and an exceedance of 5mg/l of 0%
- A concentration of 6mg/l present for 2hrs over the same 10hr analysis period would result in the same exceedance of 0.1mg/l and 1mg/l of 20%, but also an exceedance of 5mg/l of 20%

Incremental TSS results are presented at fixed heights above the seabed (5m and 20m) for the collector and at a fixed water depth (1050m) for the mid-water column discharge (i.e. 50m below the discharge port). As exceedance is influenced by the duration over which the statistics are calculated, results are presented for a statistical period starting from when production commences, finishing 24hrs and 48hrs after production stops.

For each figure, the boundary of the Area 6 pilot test is shown, with Universal Transverse Mactator (UTM) co-ordinates overlaid, to provide scale.

3.1 Scenario STR1b Results

Sedimentation results for Scenario STR1b are presented in Section 3.3.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.3.2, 20m above the seabed in Section 3.3.3 and at 1050m for the mid-water column discharge in Section 3.3.4.

3.1.1 Sedimentation

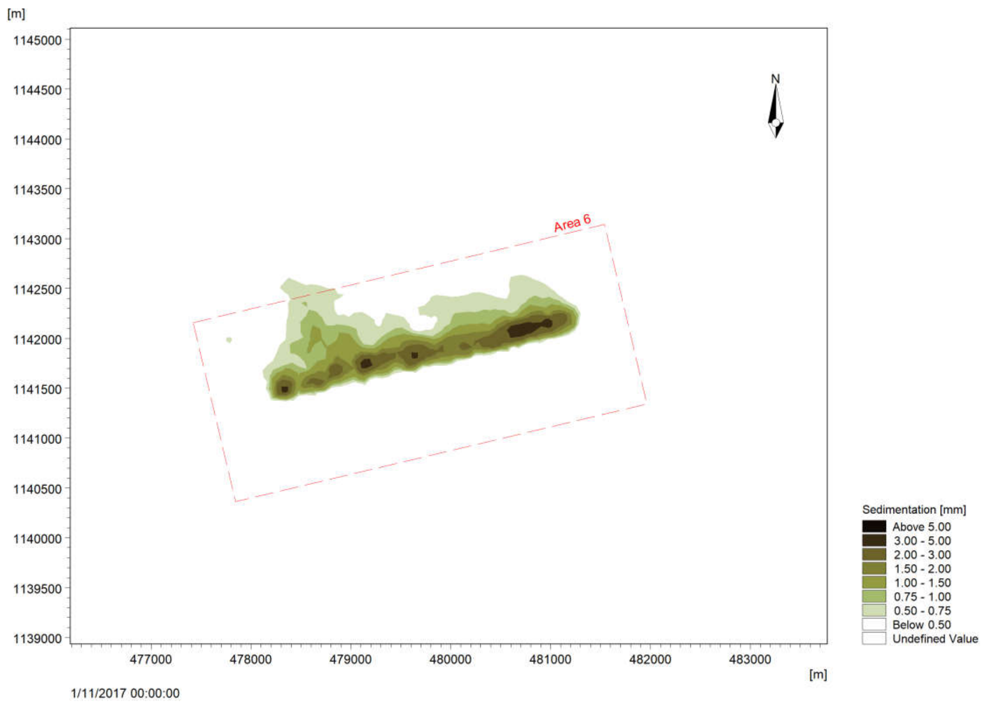

Figure 3.1 Scenario STR1b: Sedimentation (mm) at the final timestep

3.1.2 TSS 5m Above Seabed

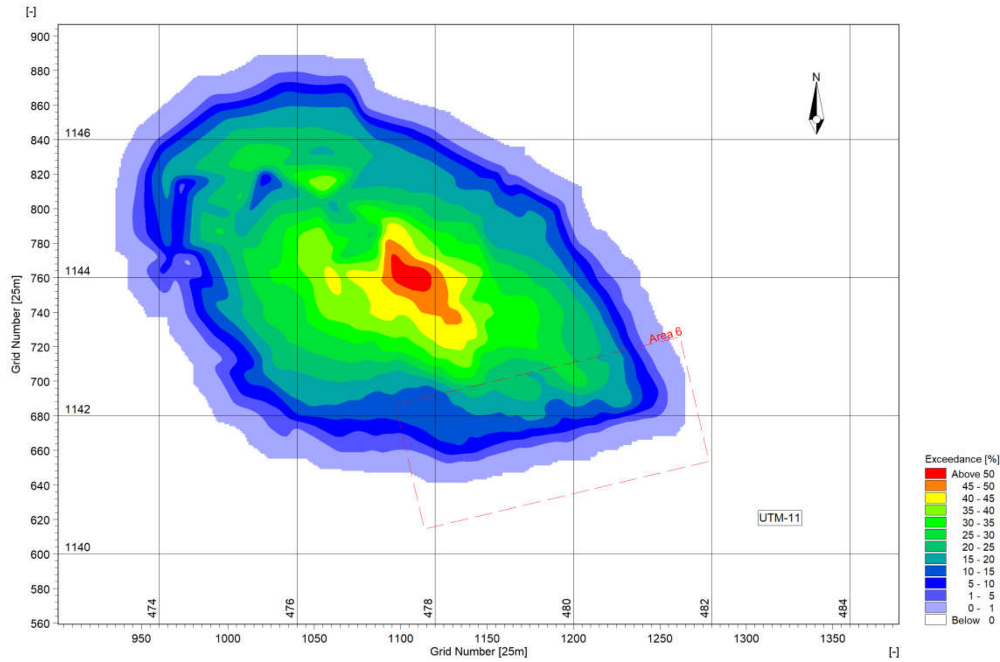

Figure 3.2 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

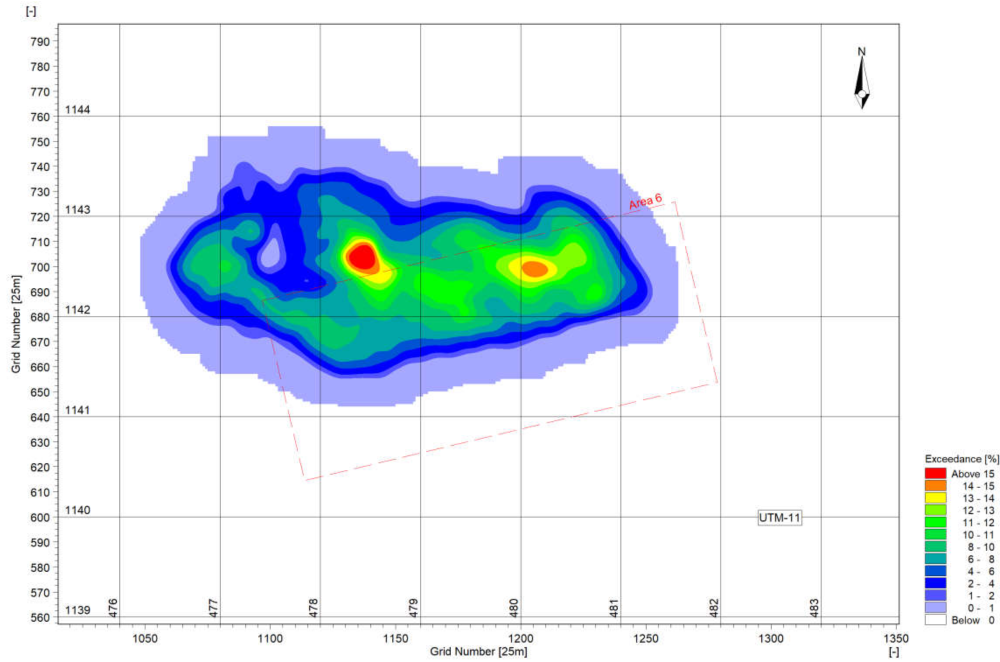

Figure 3.3 Scenario STR1b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

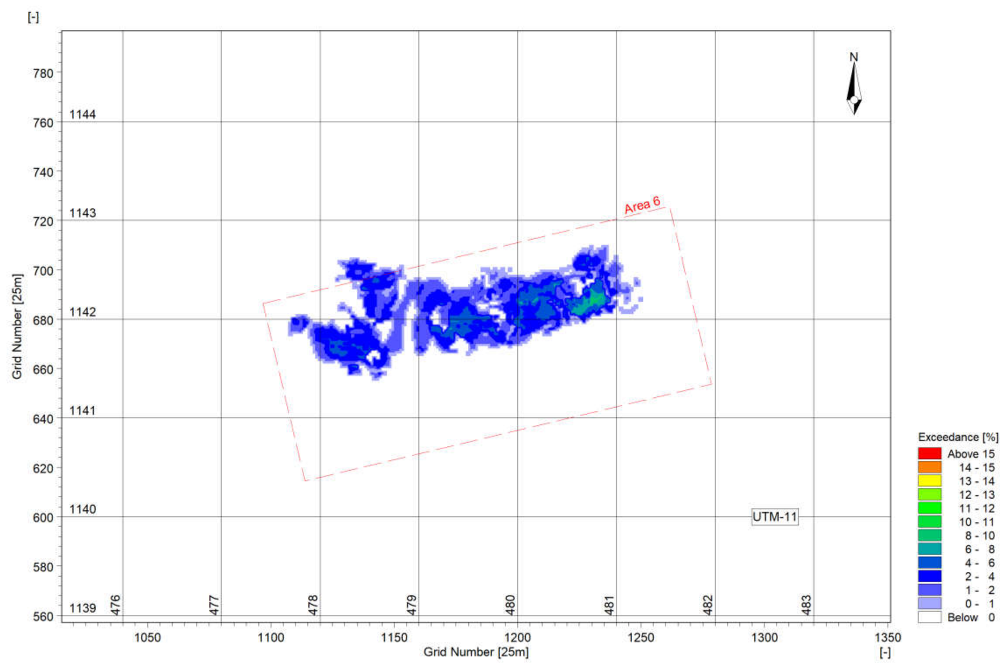

Figure 3.4 Scenario STR1b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

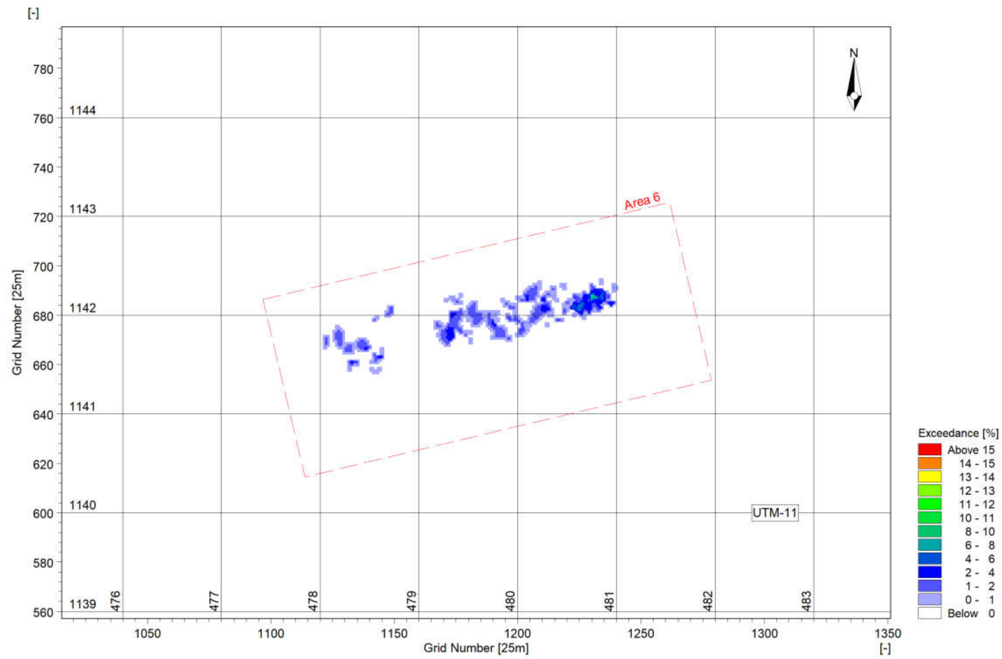

Figure 3.5 Scenario STR1b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

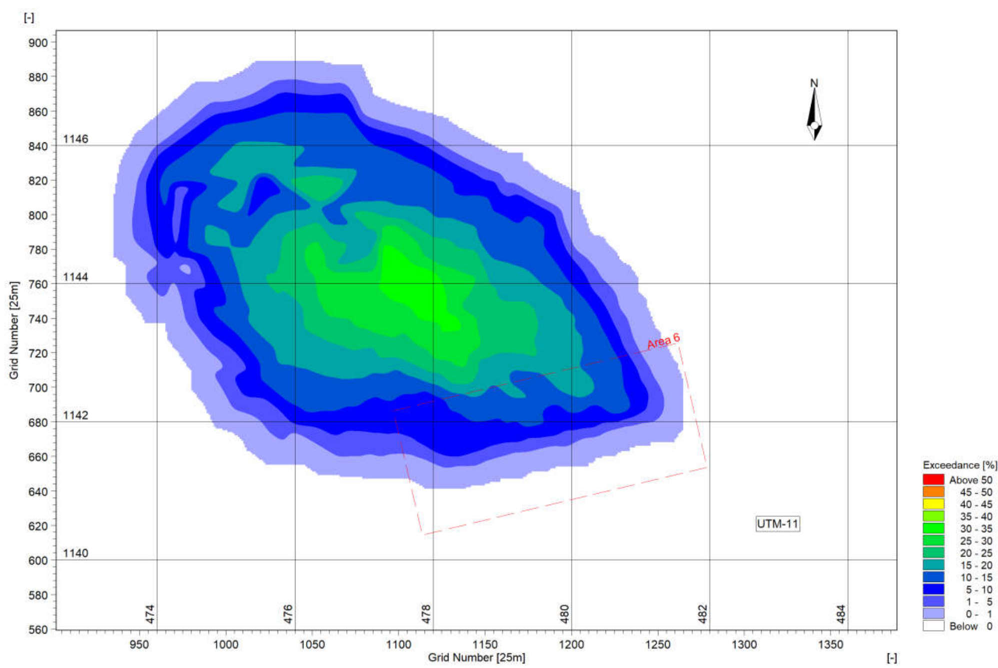

Figure 3.6 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

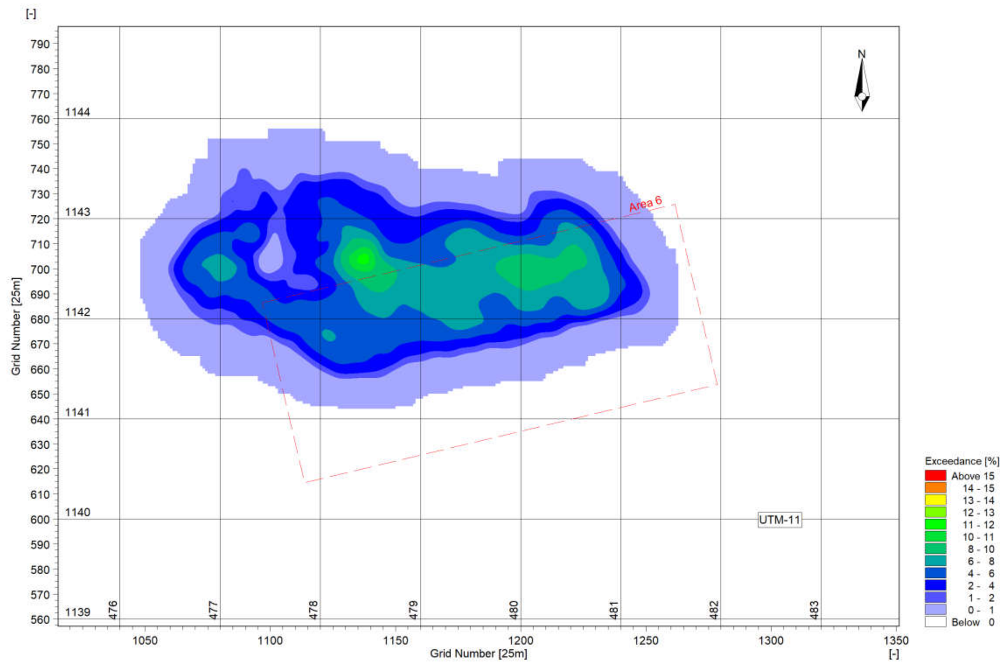

Figure 3.7 Scenario STR1b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

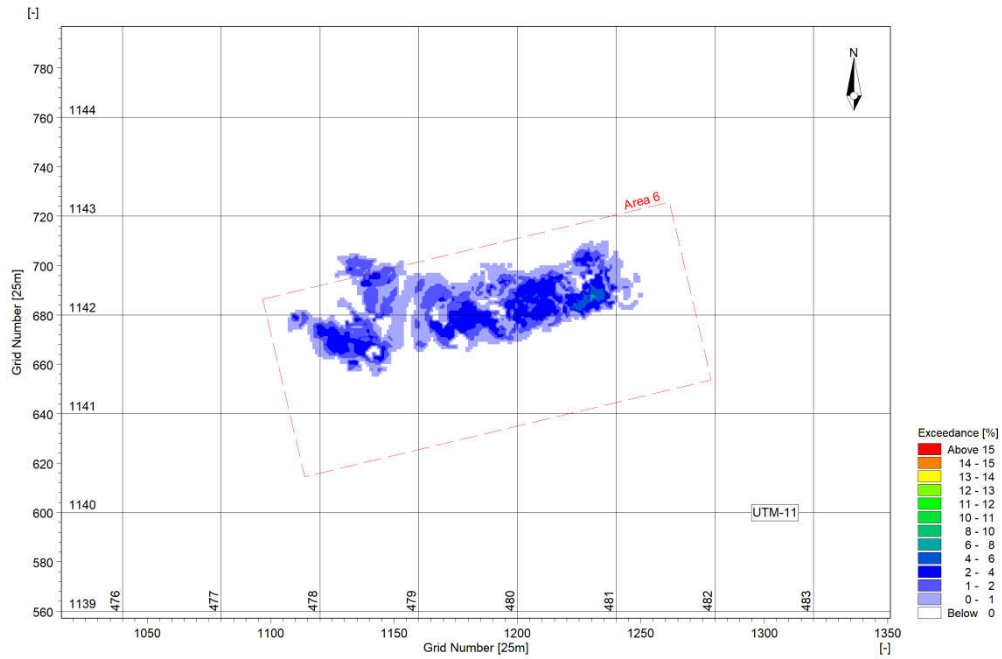

Figure 3.8 Scenario STR1b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

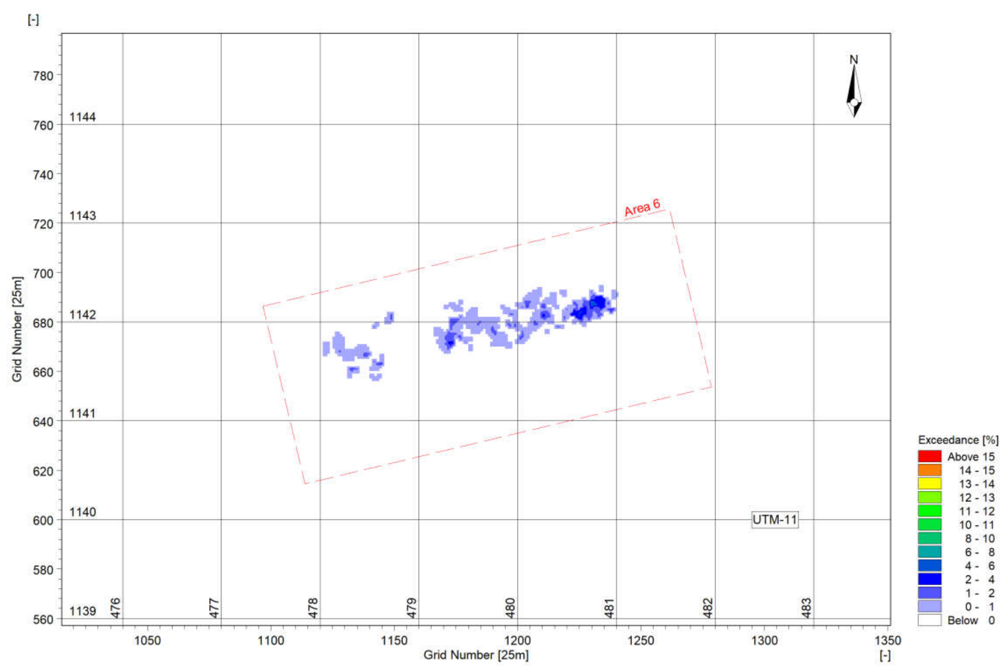

Figure 3.9 Scenario STR1b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.1.3 TSS 20m Above Seabed

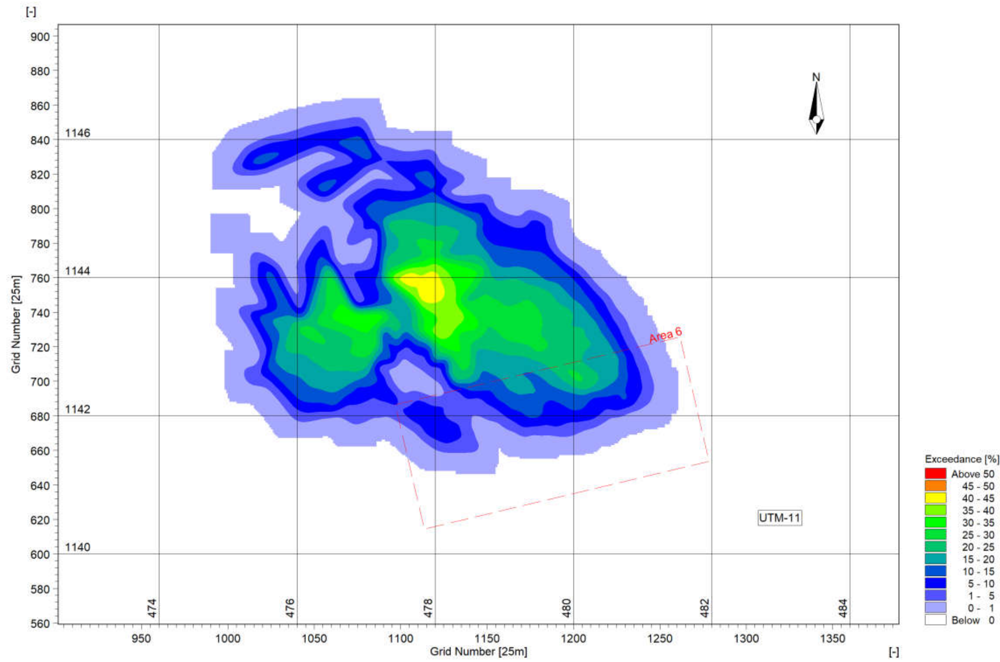

Figure 3.10 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

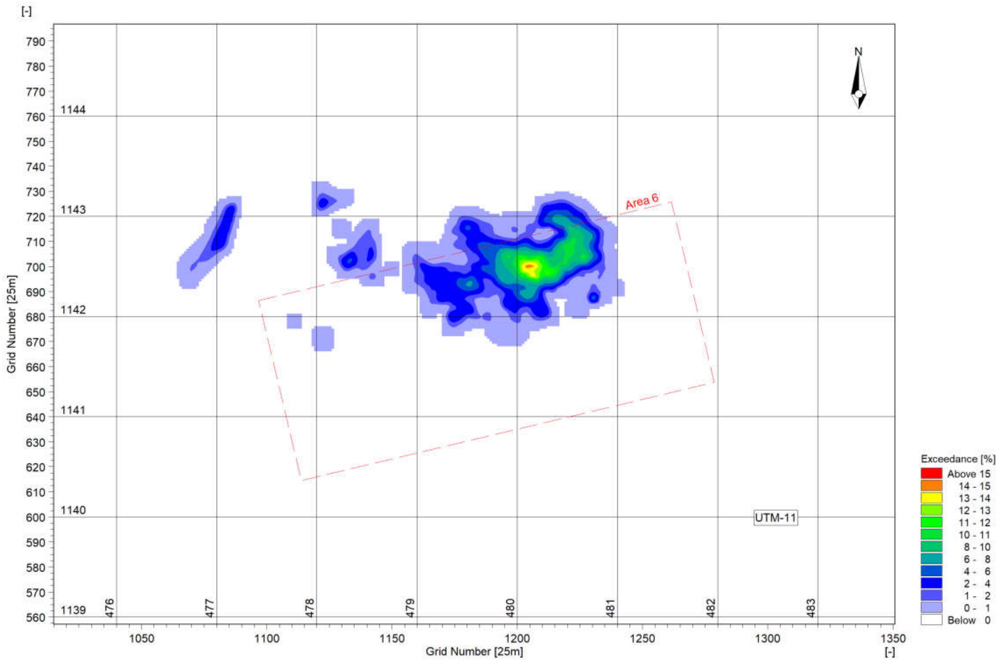

Figure 3.11 Scenario STR1b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

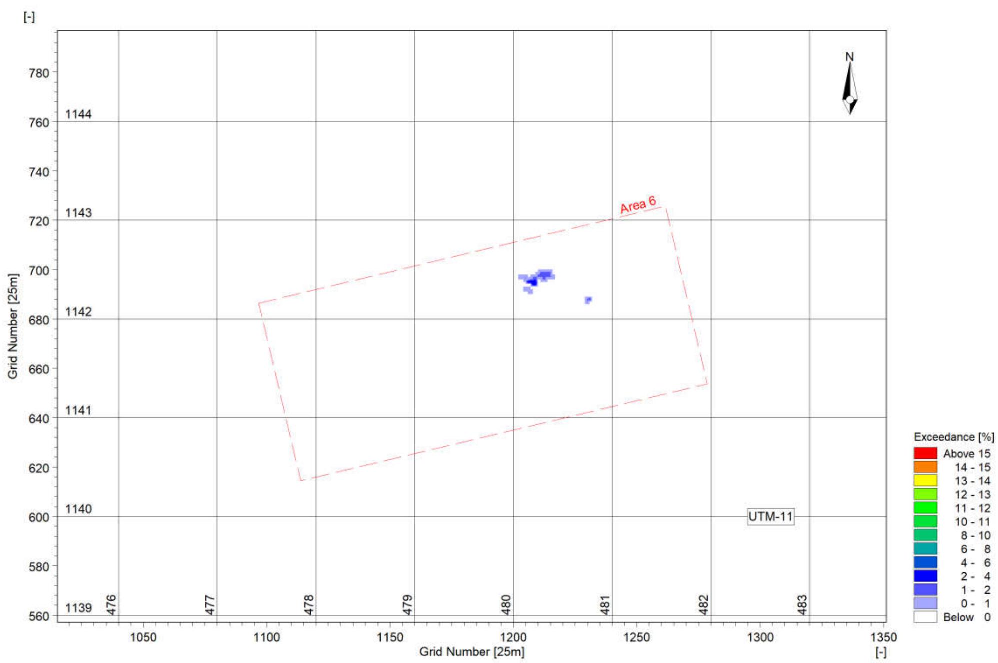

Figure 3.12 Scenario STR1b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

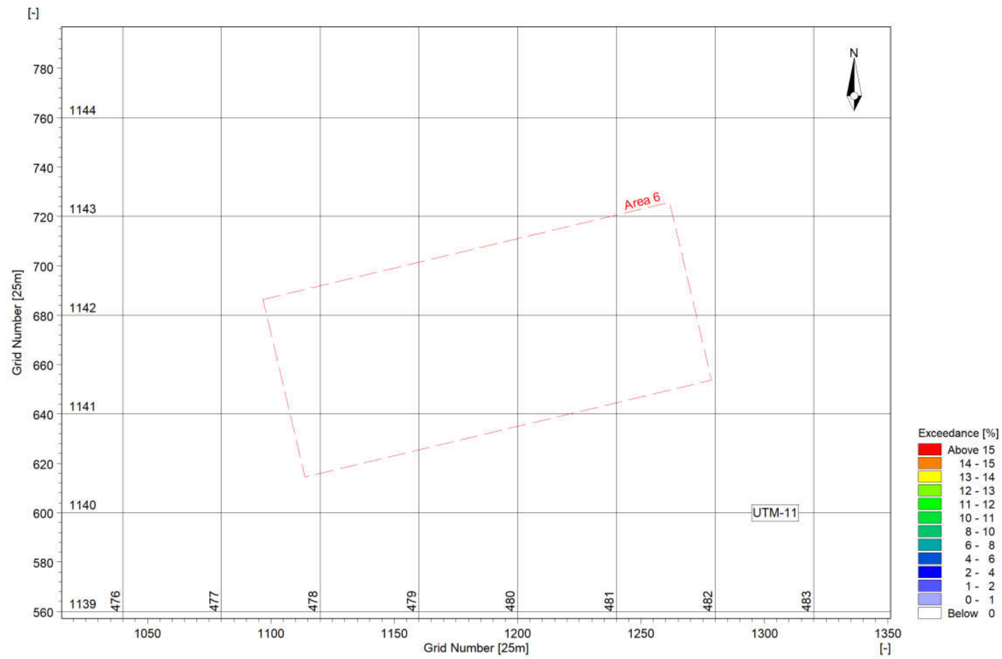

Figure 3.13 Scenario STR1b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

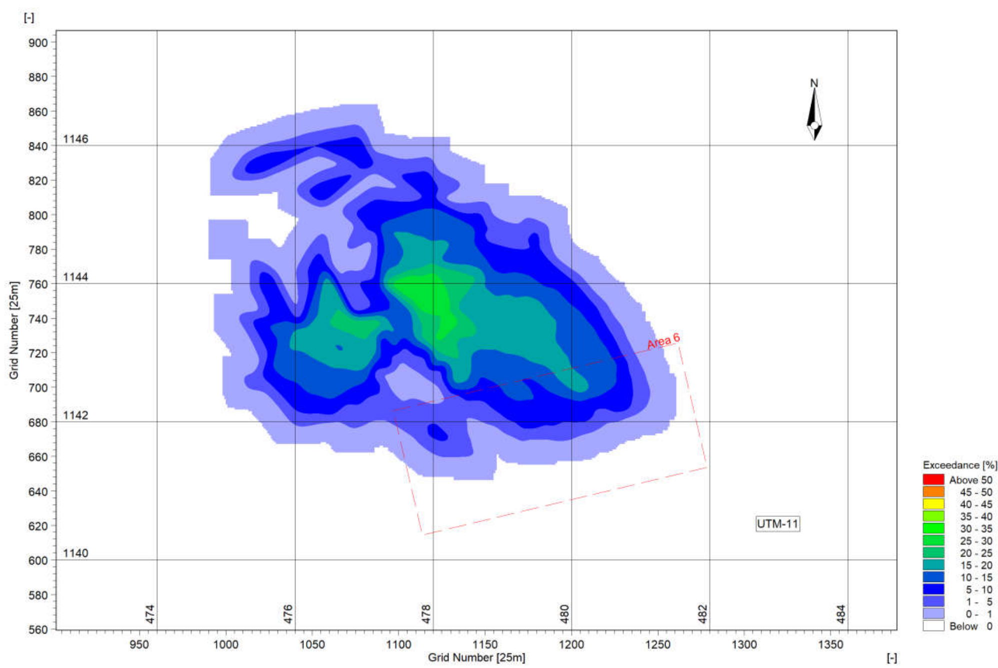

Figure 3.14 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

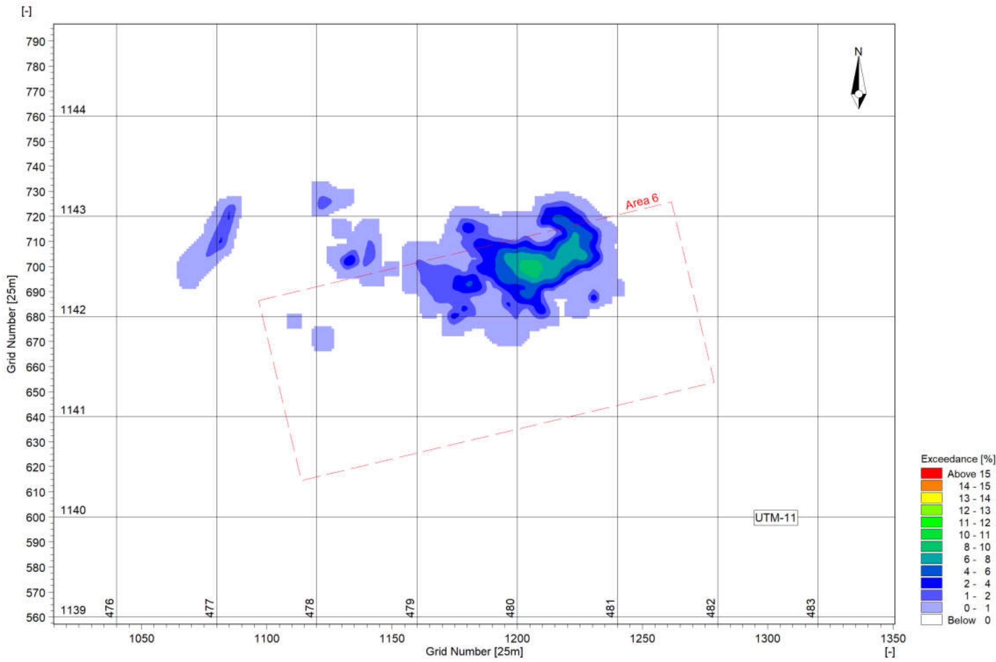

Figure 3.15 Scenario STR1b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

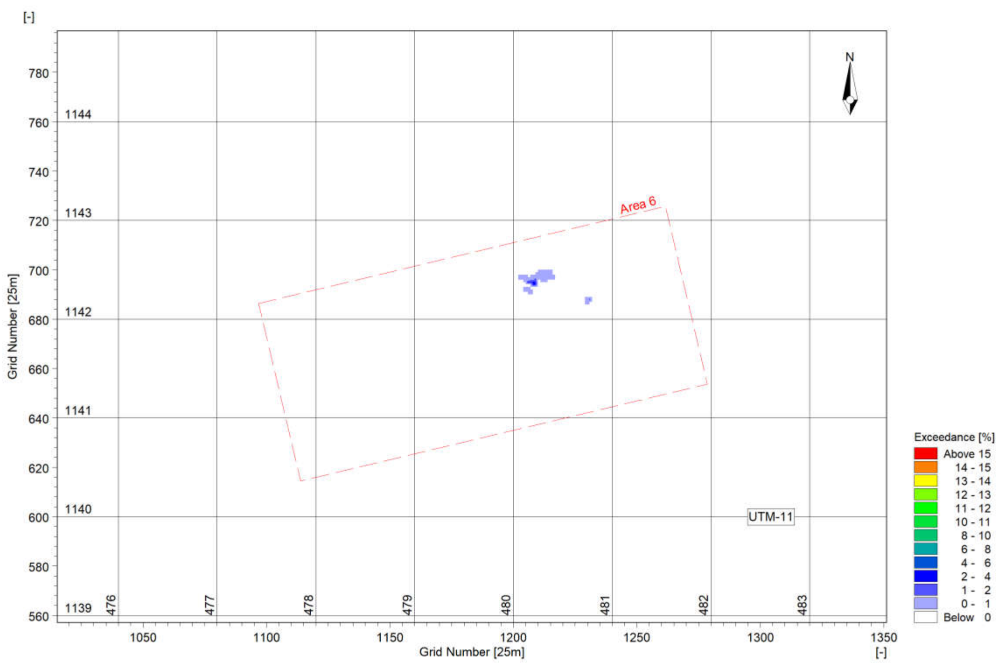

Figure 3.16 Scenario STR1b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

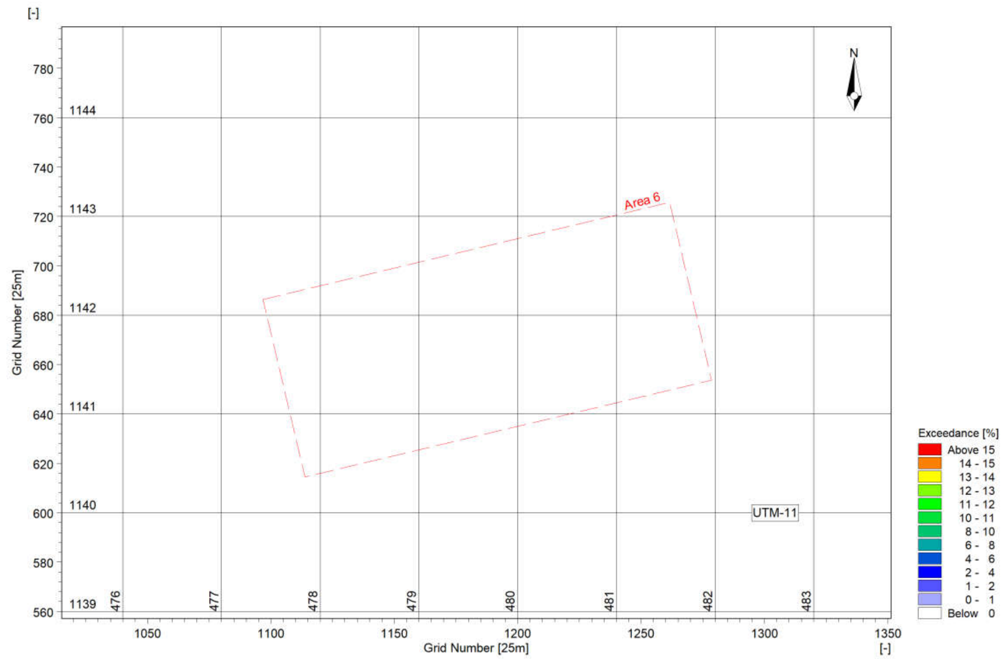

Figure 3.17 Scenario STR1b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.1.4 TSS at Mid-Water Column Discharge

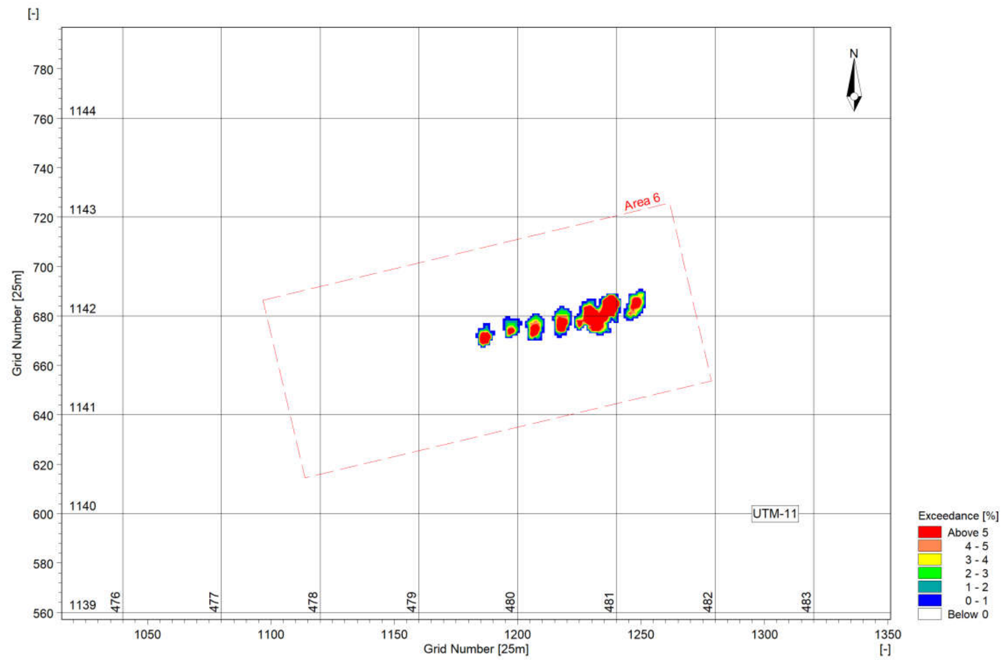

Figure 3.18 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

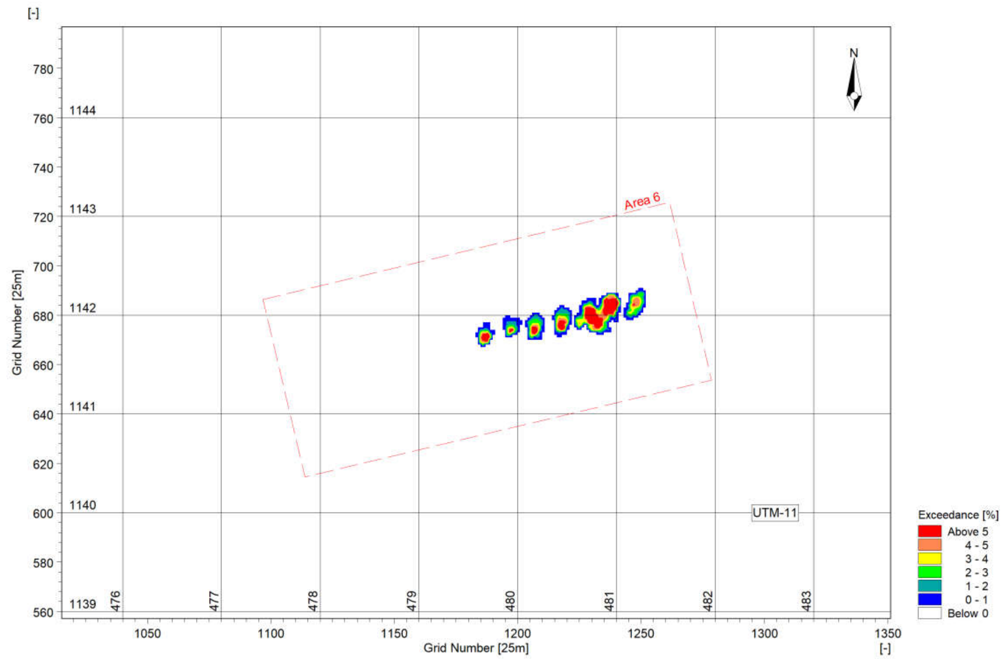

Figure 3.19 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

3.2 Scenario STR2a Results

Sedimentation results for Scenario STR2a are presented in Section 3.1.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.1.2, 20m above the seabed in Section 3.1.3 and at 1050m for the mid-water column discharge in Section 3.1.4.

3.2.1 Sedimentation

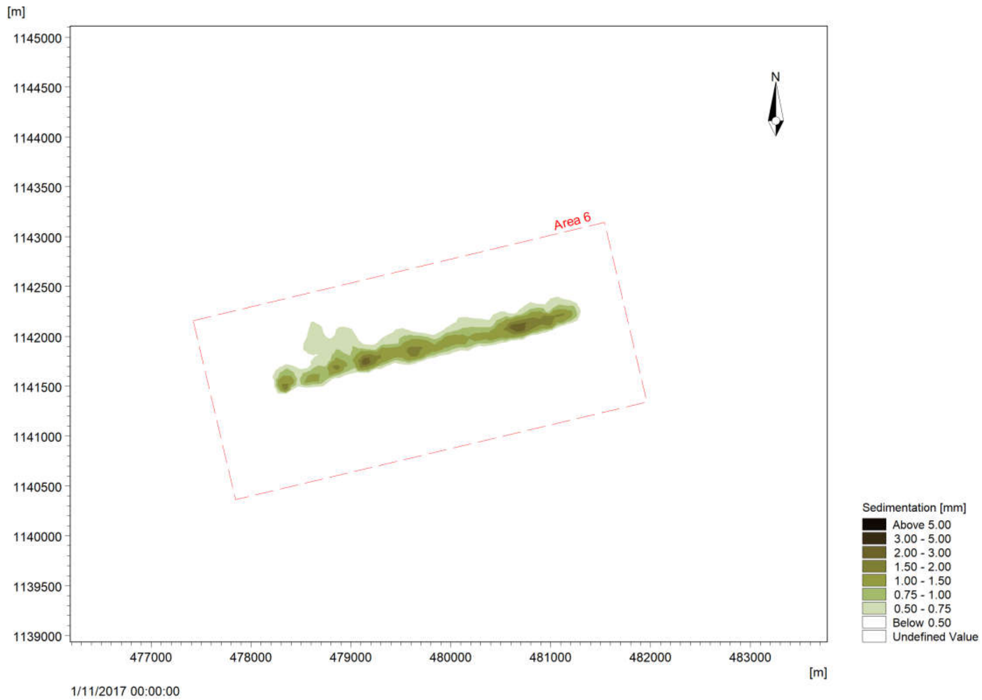

Figure 3.20 Scenario STR2a: Sedimentation (mm) at the final timestep

3.2.2 TSS 5m Above Seabed

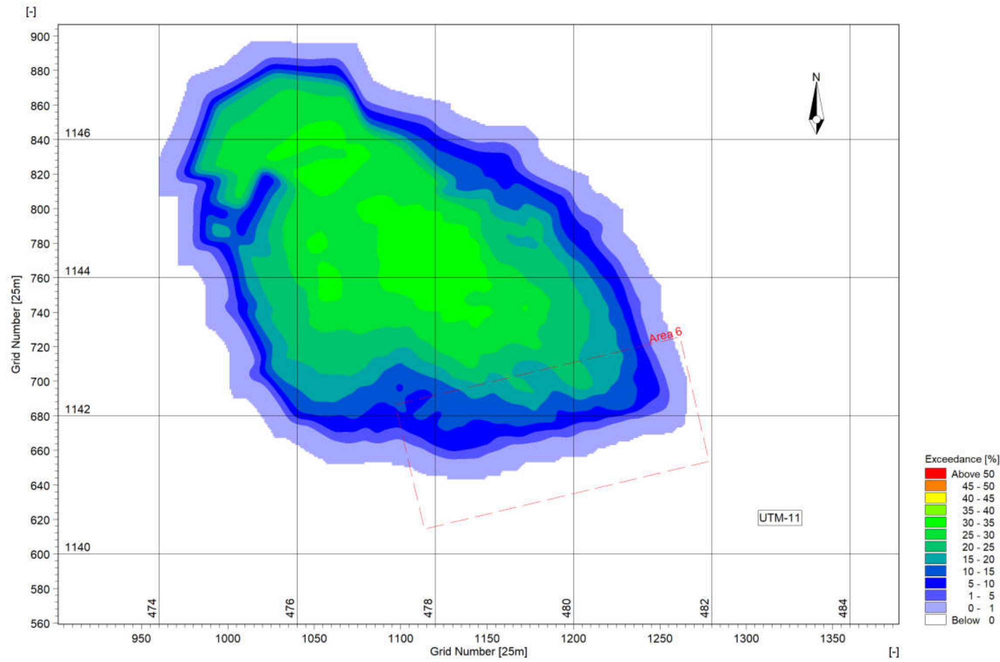

Figure 3.21 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

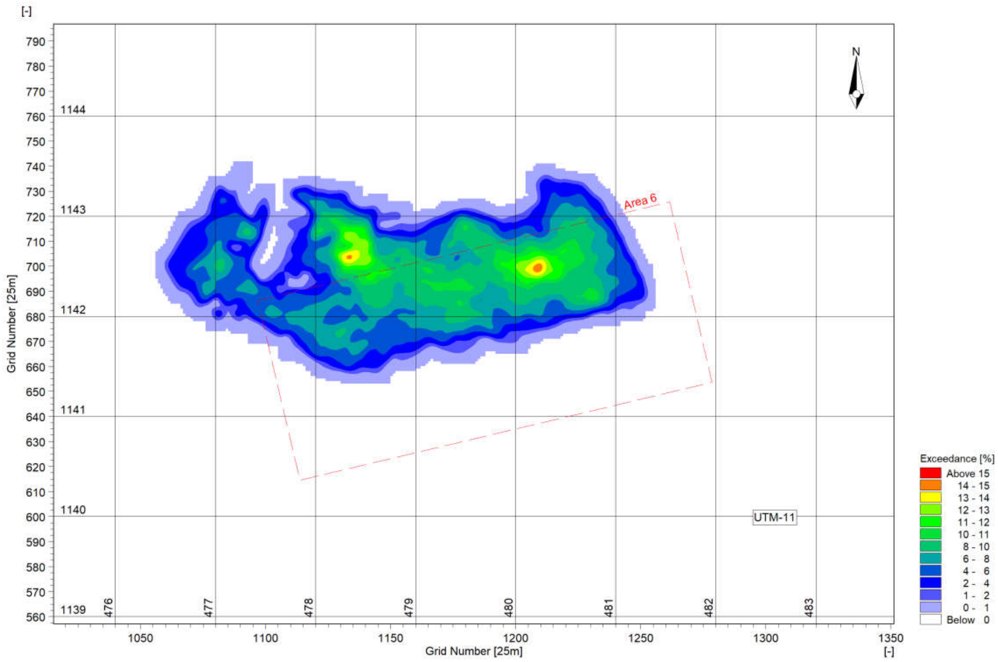

Figure 3.22 Scenario STR2a: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

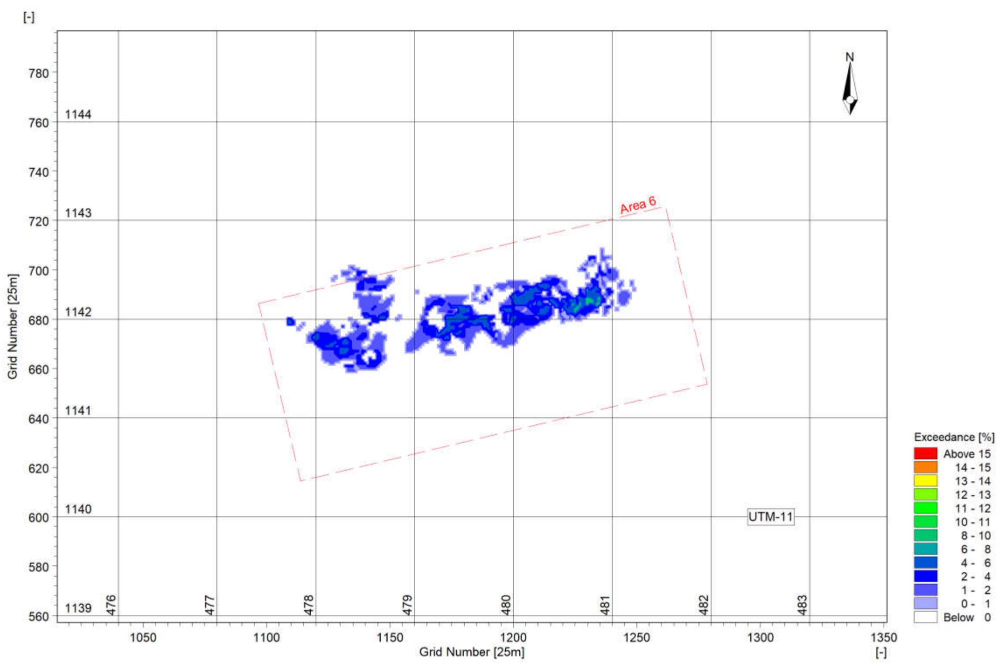

Figure 3.23 Scenario STR2a: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

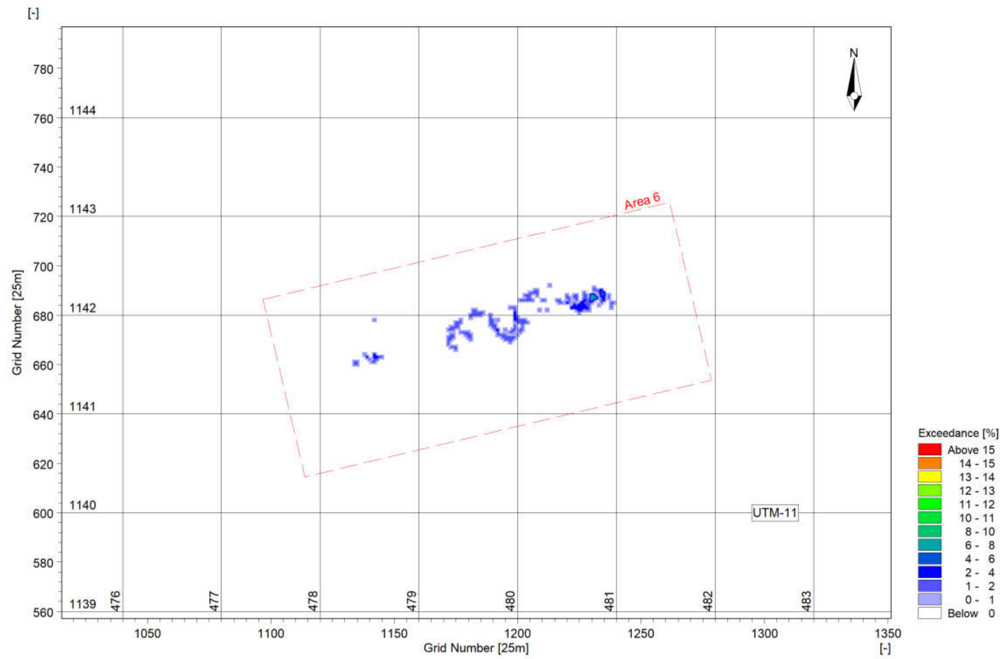

Figure 3.24 Scenario STR2a: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

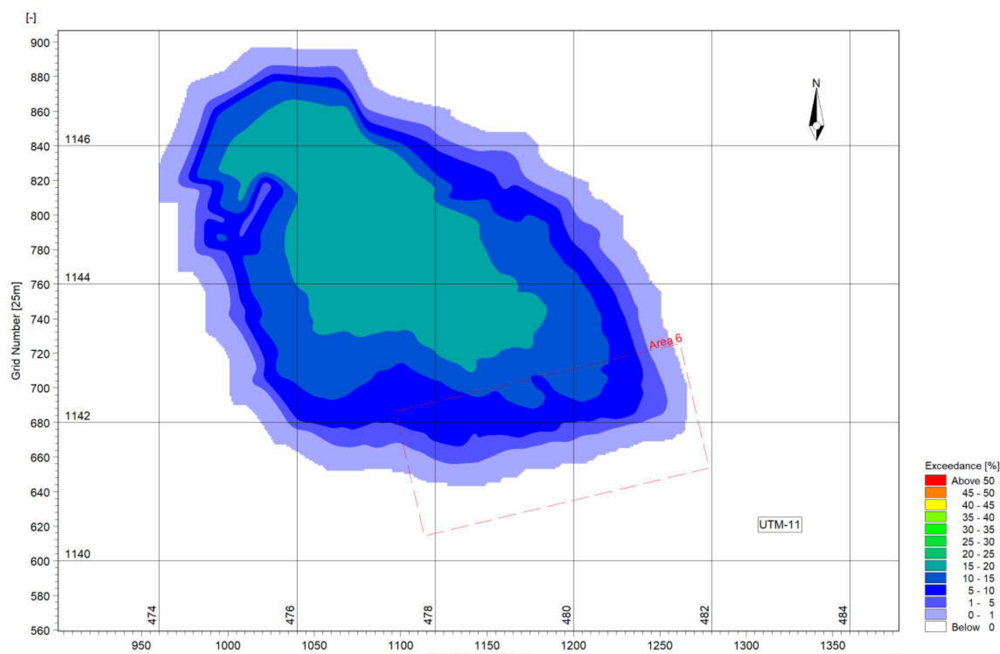

Figure 3.25 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

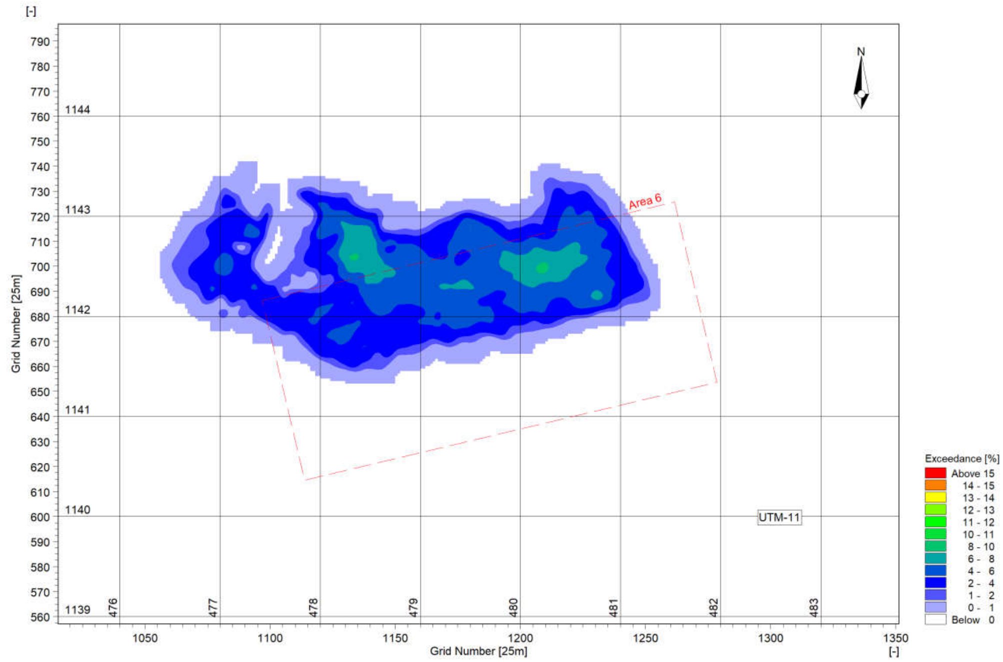

Figure 3.26 Scenario STR2a: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

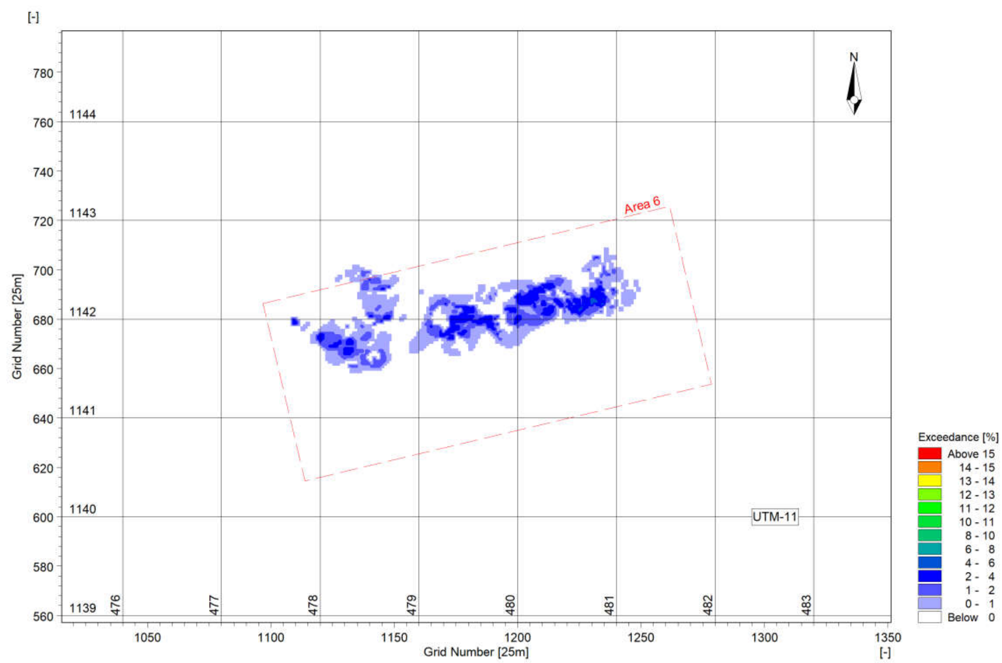

Figure 3.27 Scenario STR2a: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

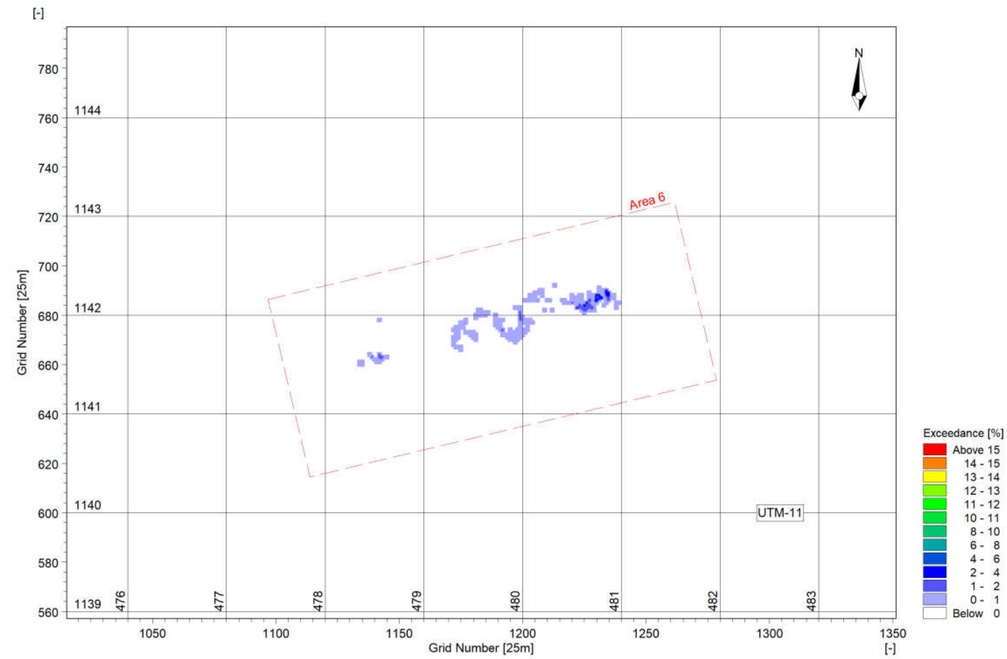

Figure 3.28 Scenario STR2a: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.2.3 TSS 20m Above Seabed

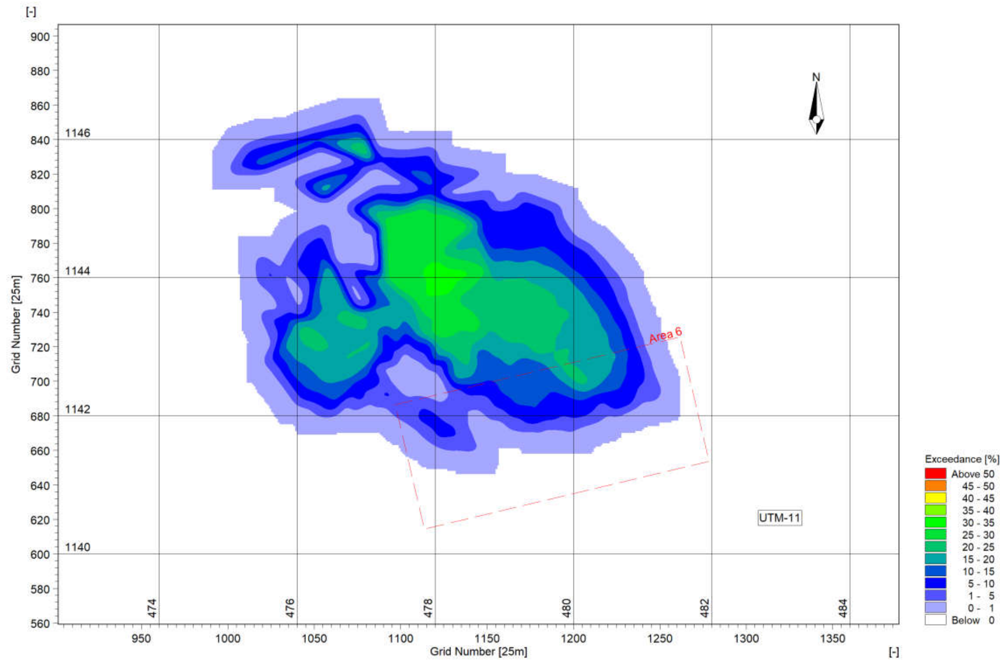

Figure 3.29 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

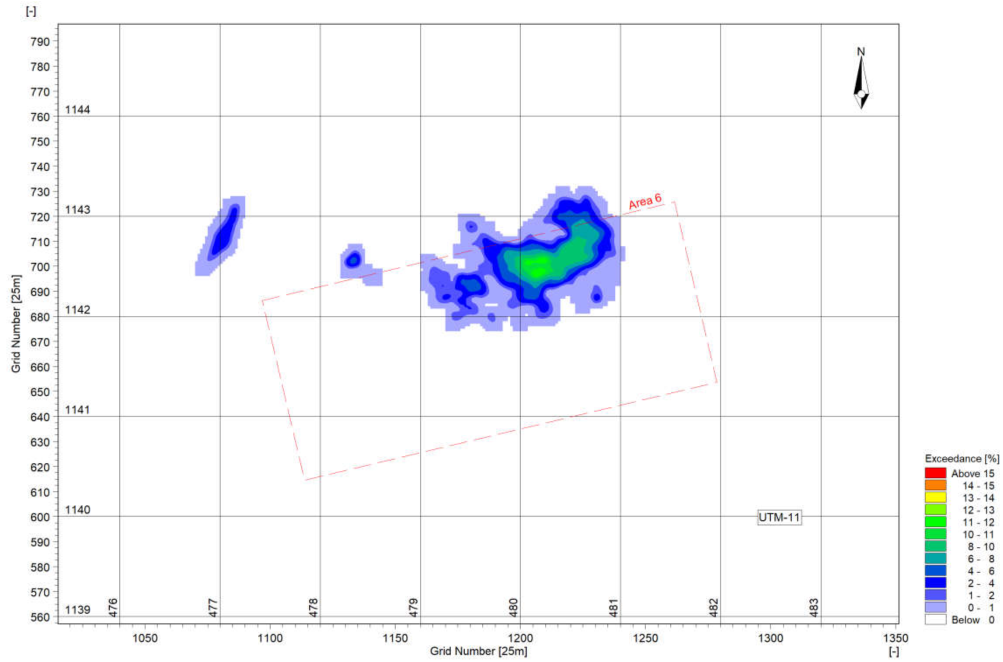

Figure 3.30 Scenario STR2a: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

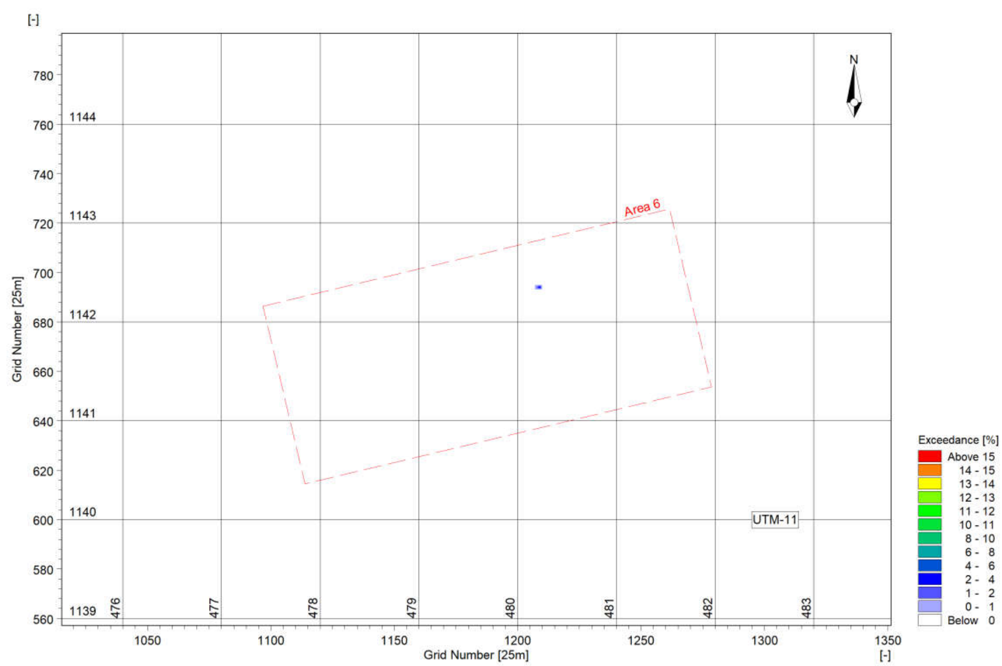

Figure 3.31 Scenario STR2a: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

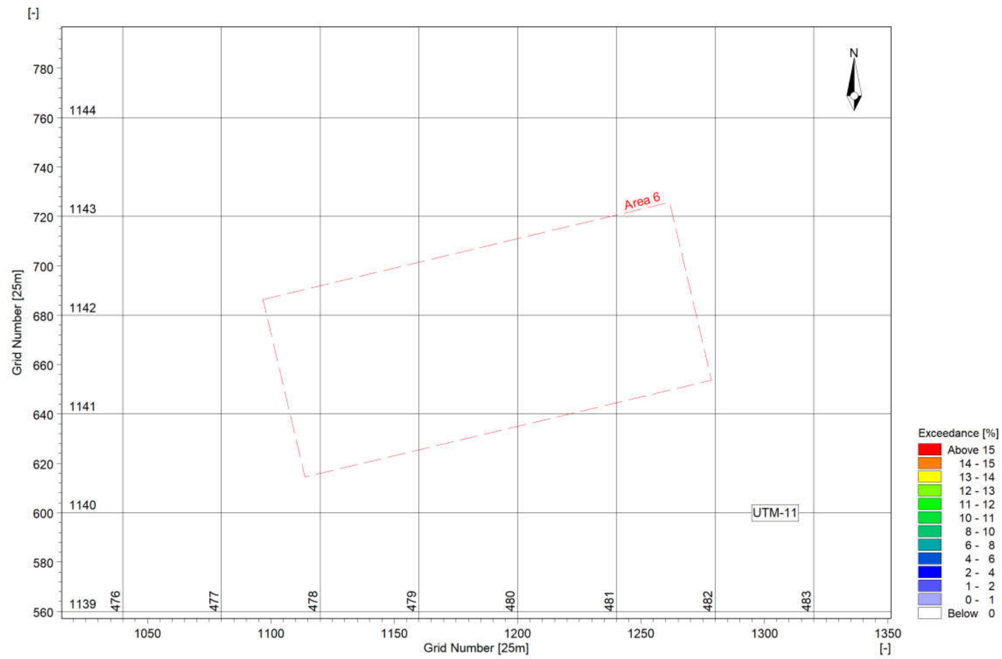

Figure 3.32 Scenario STR2a: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

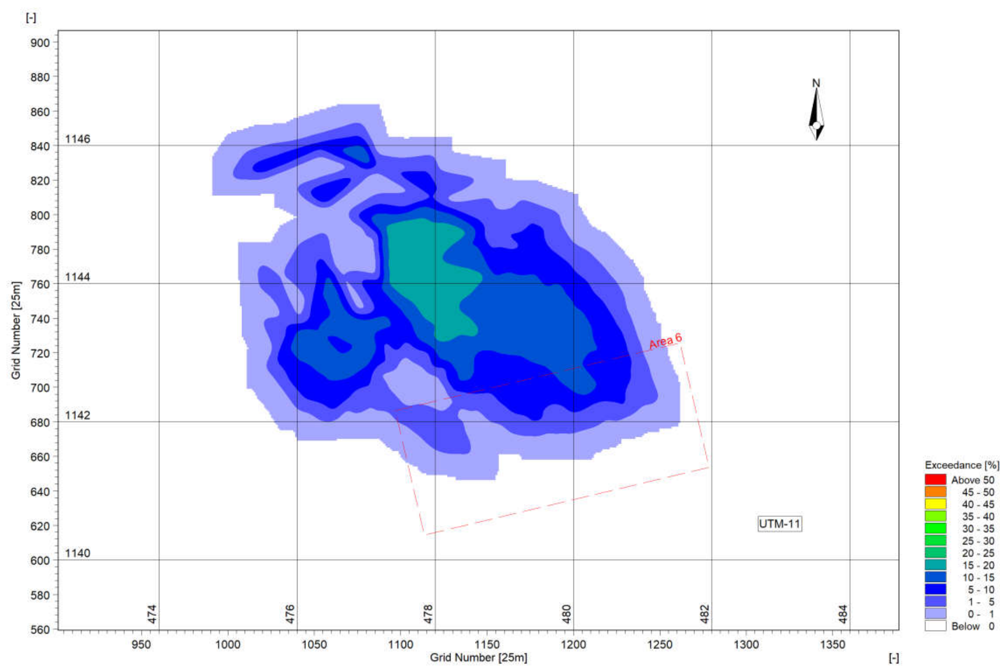

Figure 3.33 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

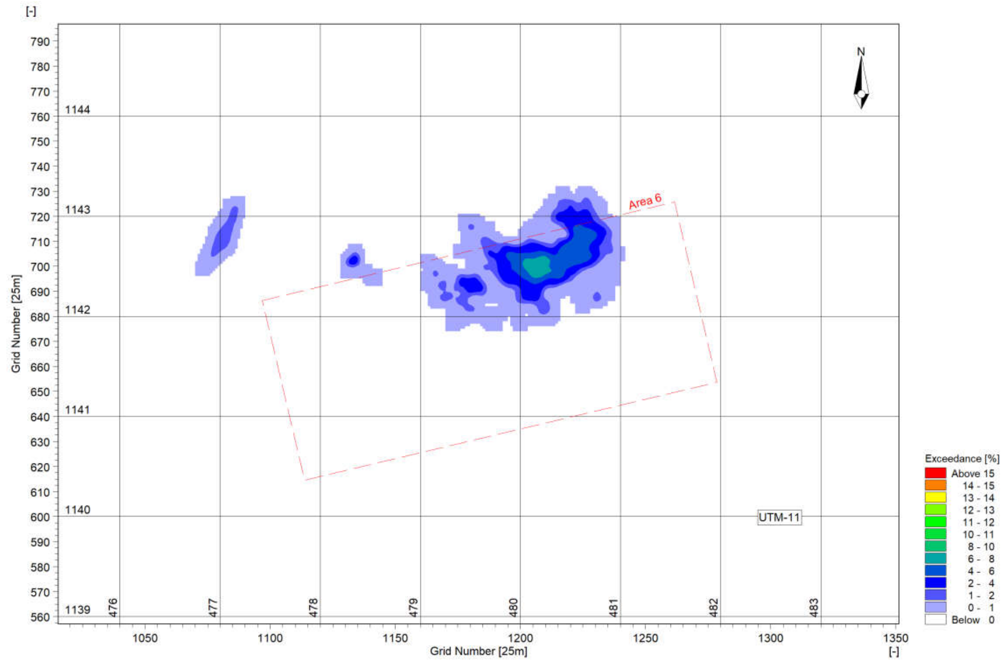

Figure 3.34 Scenario STR2a: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

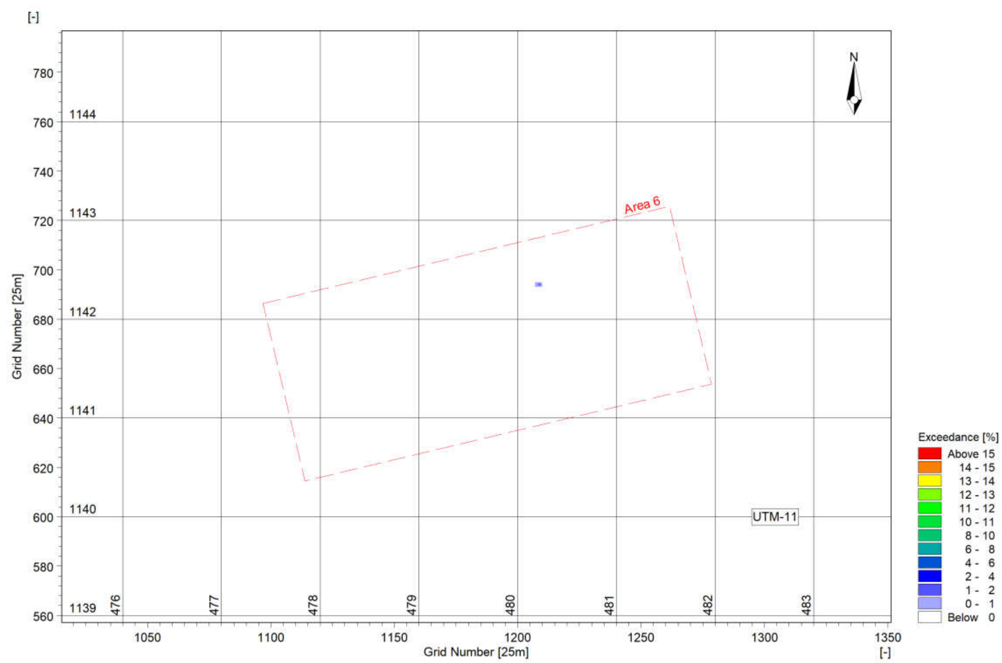

Figure 3.35 Scenario STR2a: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

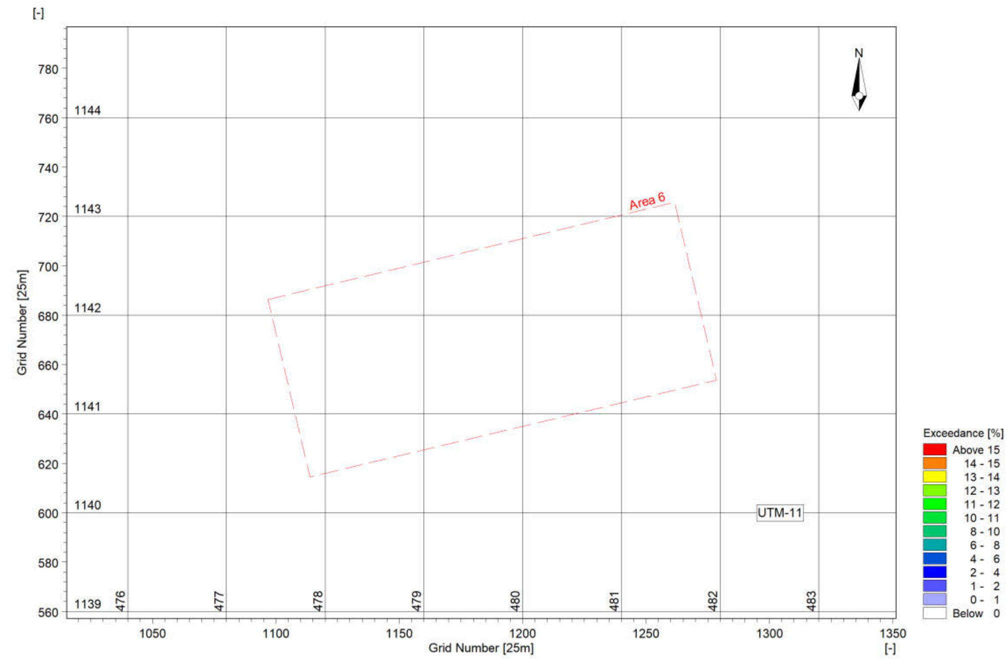

Figure 3.36 Scenario STR2a: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.2.4 TSS at Mid-Water Column Discharge

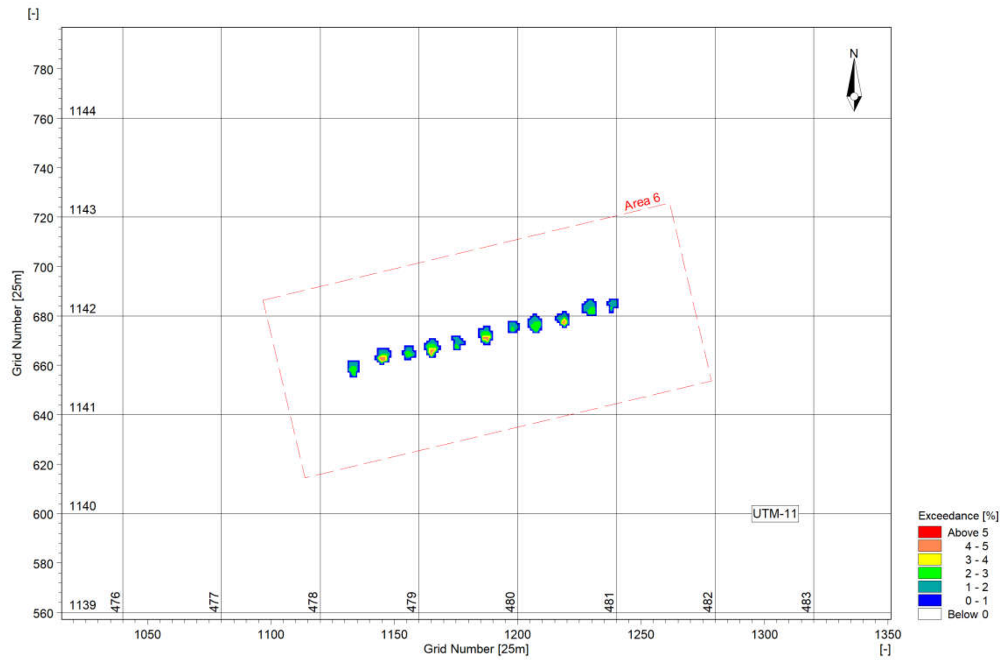

Figure 3.37 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

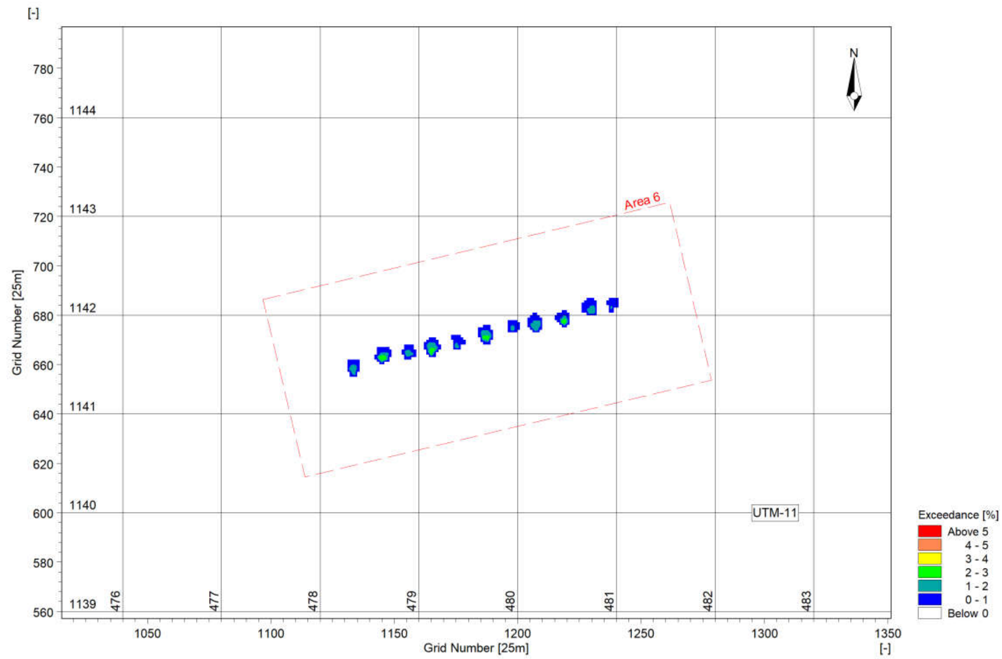

Figure 3.38 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

3.3 Scenario STR2b Results

Sedimentation results for Scenario STR2b are presented in Section 3.4.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.3.2, 20m above the seabed in Section 3.4.3 and at 1050m for the mid-water column discharge in Section 3.4.4.

3.3.1 Sedimentation

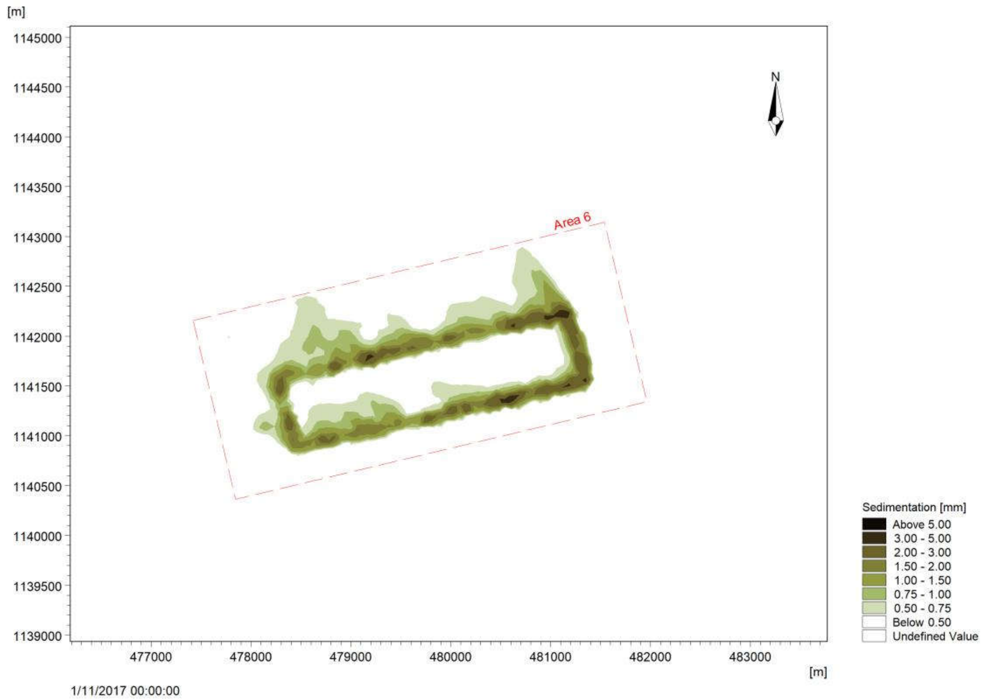

Figure 3.39 Scenario STR2b: Sedimentation (mm) at the final timestep

3.3.2 TSS 5m Above Seabed

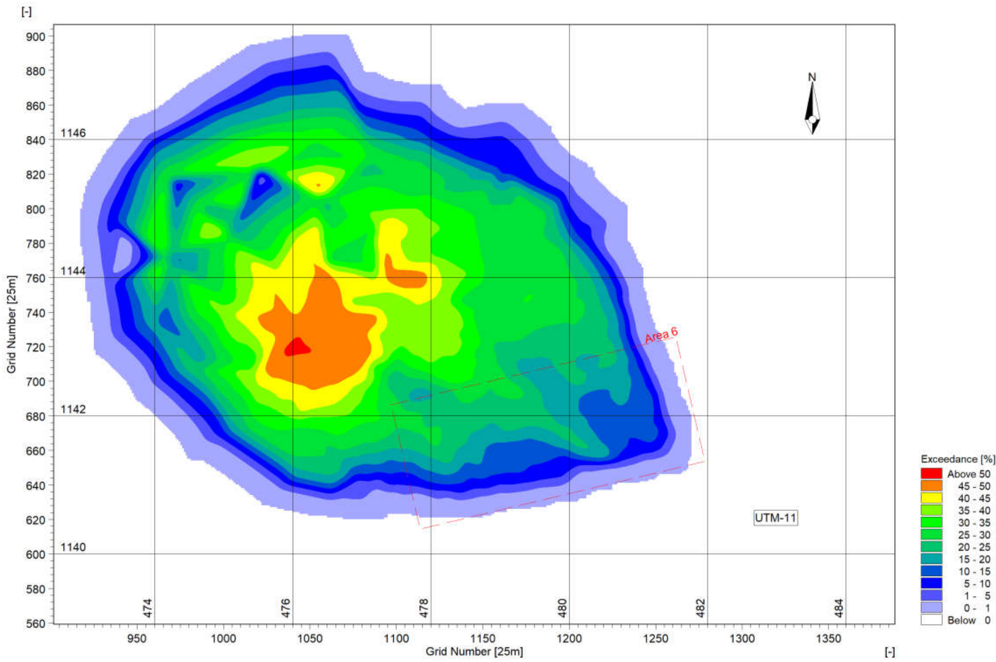

Figure 3.40 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

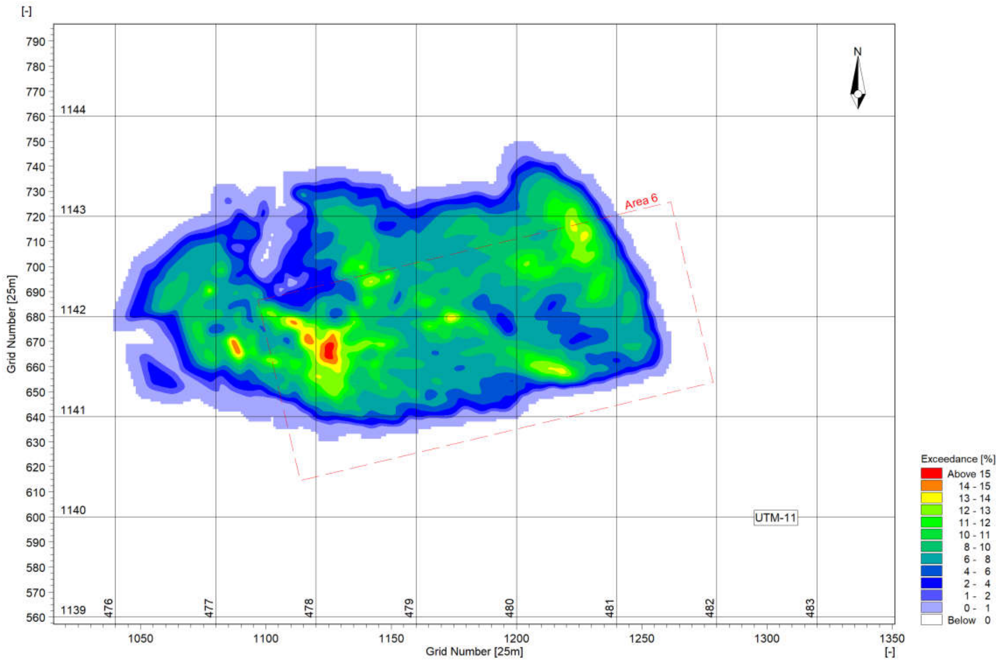

Figure 3.41 Scenario STR2b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

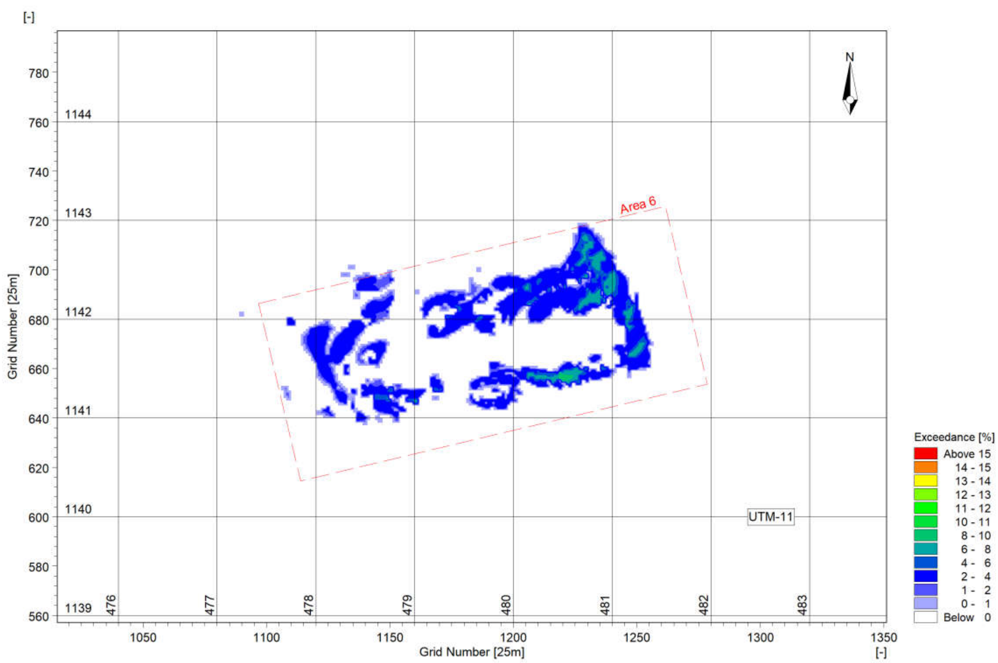

Figure 3.42 Scenario STR2b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

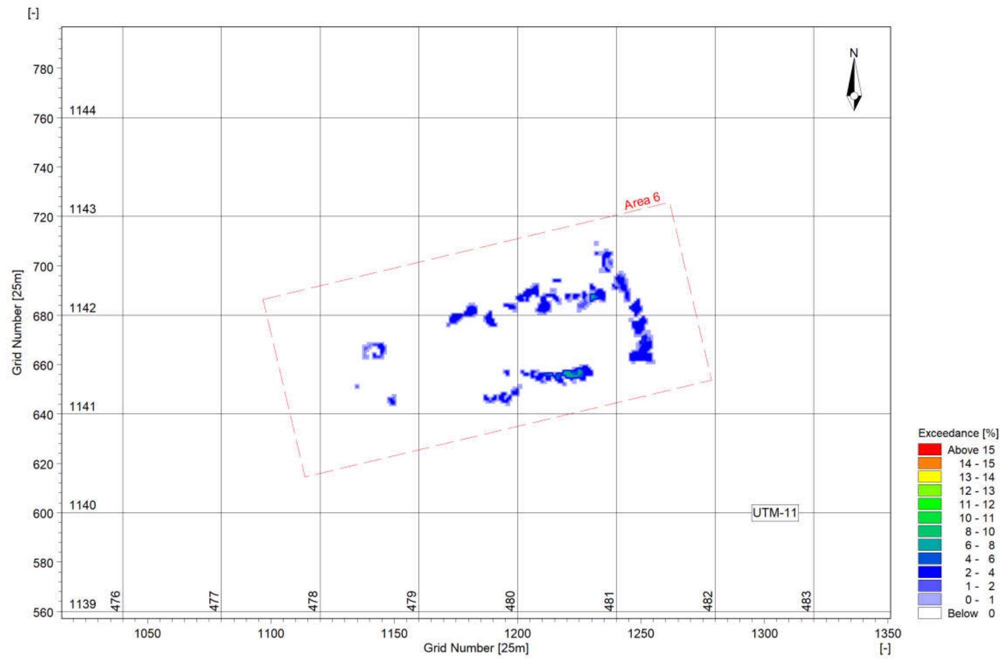

Figure 3.43 Scenario STR2b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

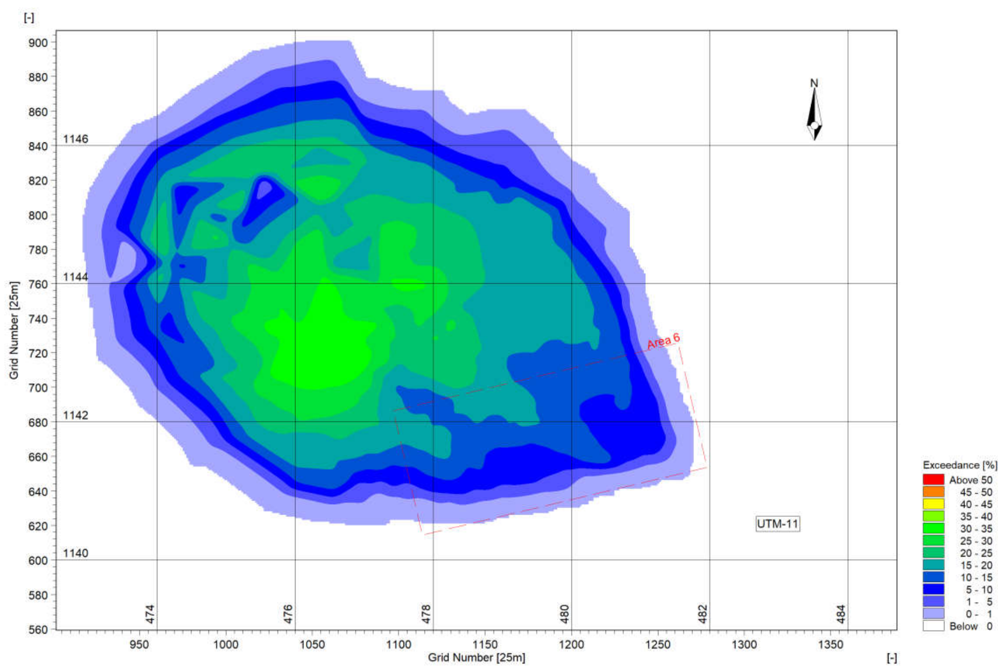

Figure 3.44 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

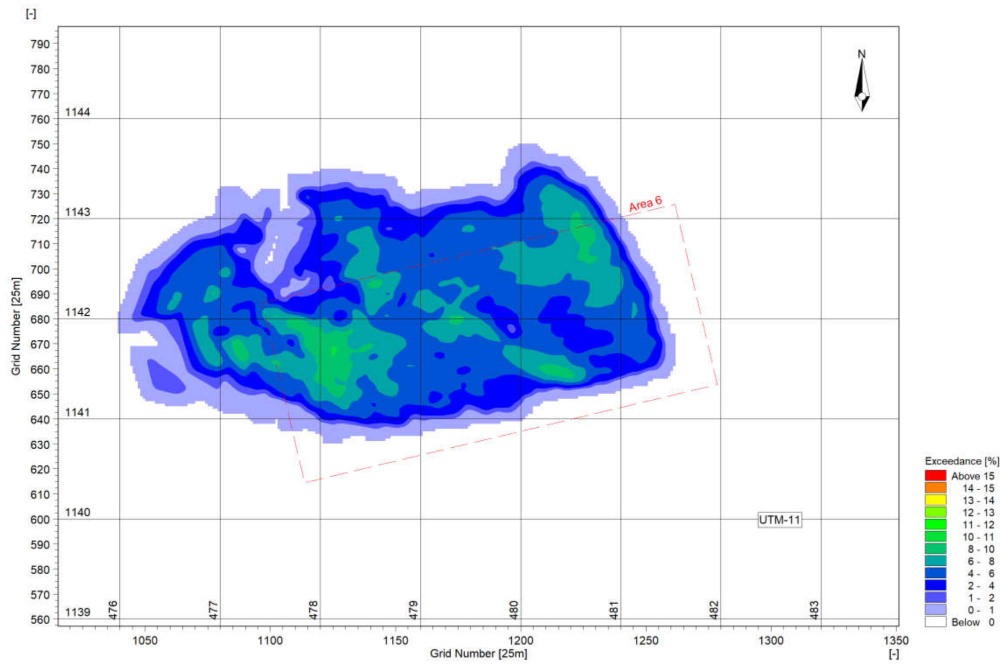

Figure 3.45 Scenario STR2b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

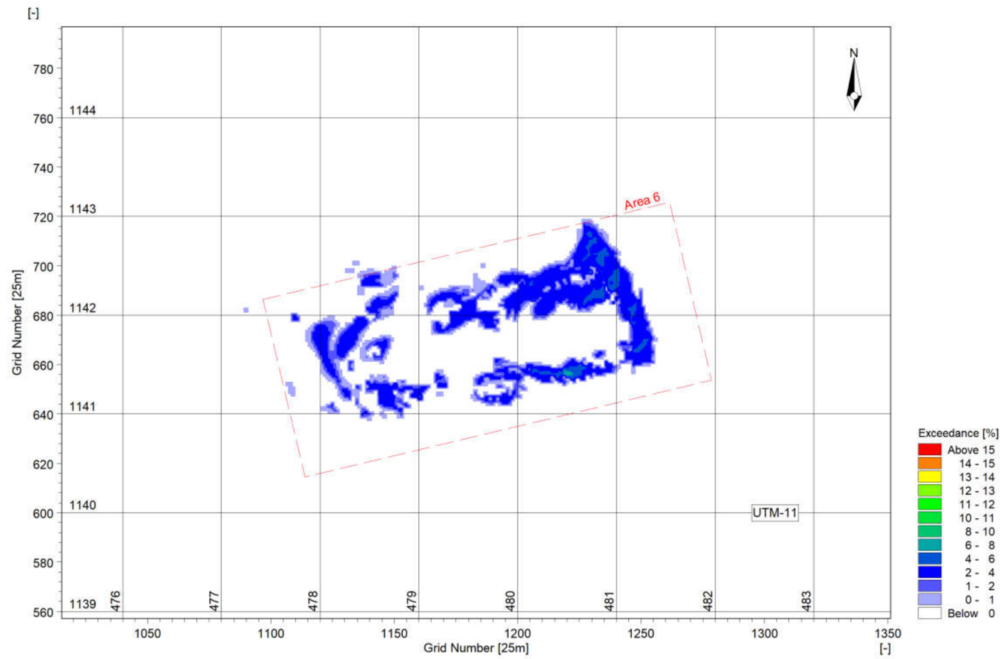

Figure 3.46 Scenario STR2b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

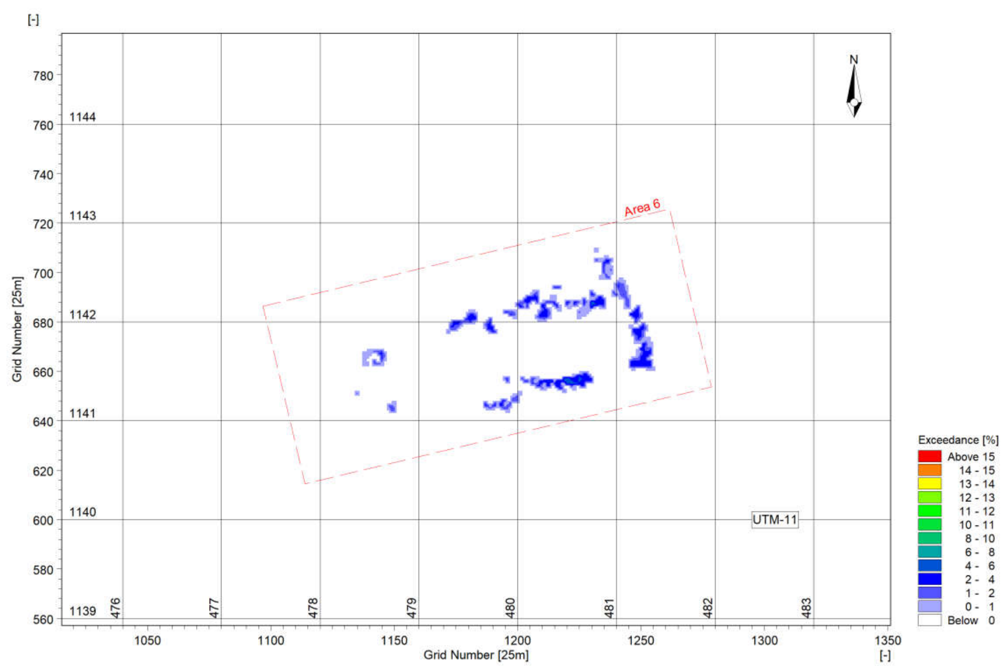

Figure 3.47 Scenario STR2b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.3.3 TSS 20m Above Seabed

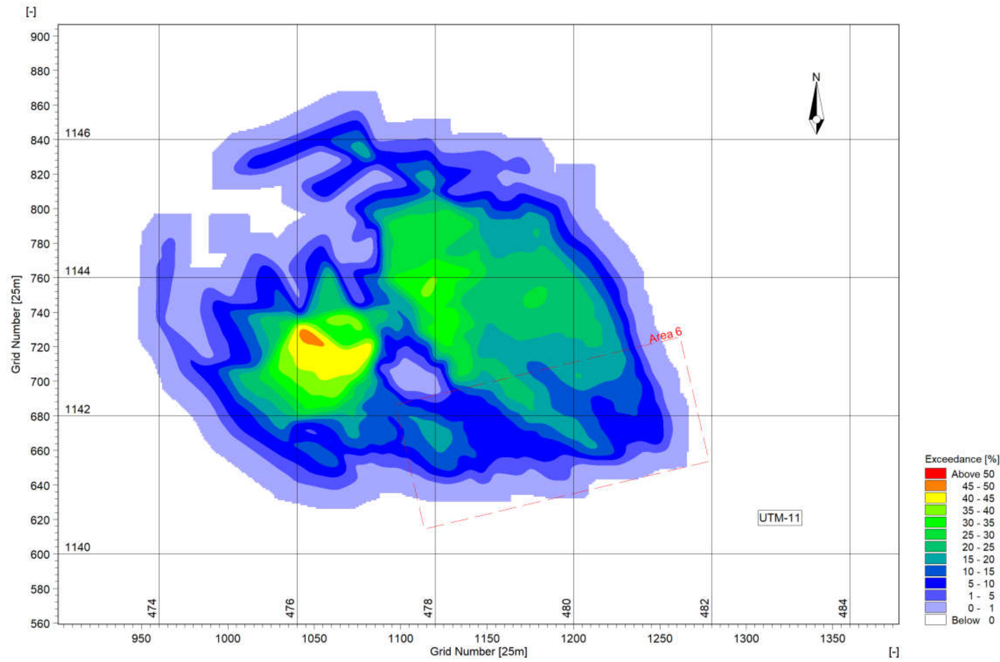

Figure 3.48 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

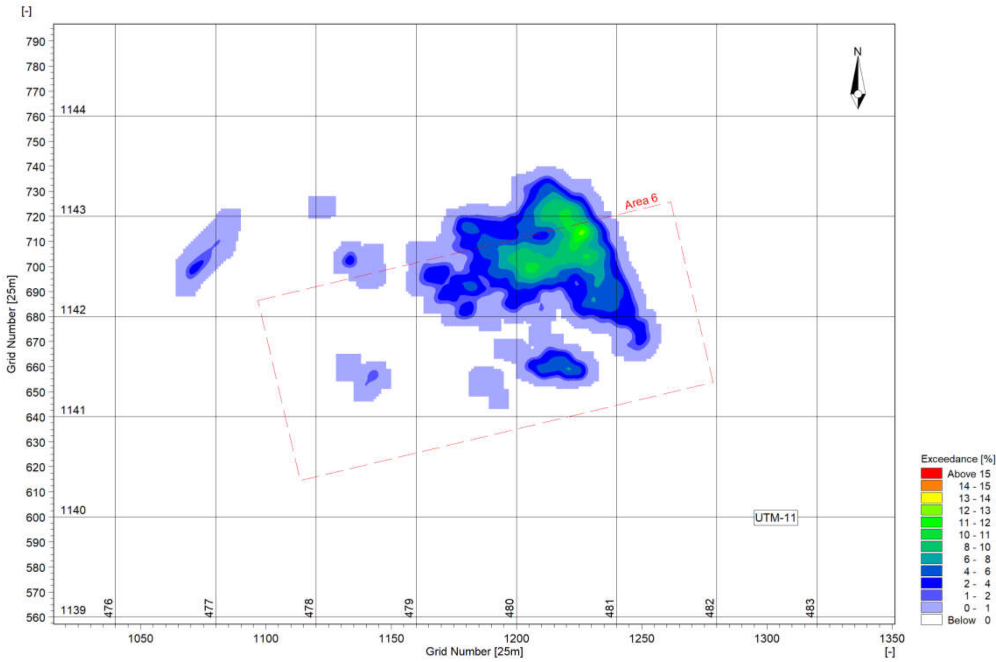

Figure 3.49 Scenario STR2b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

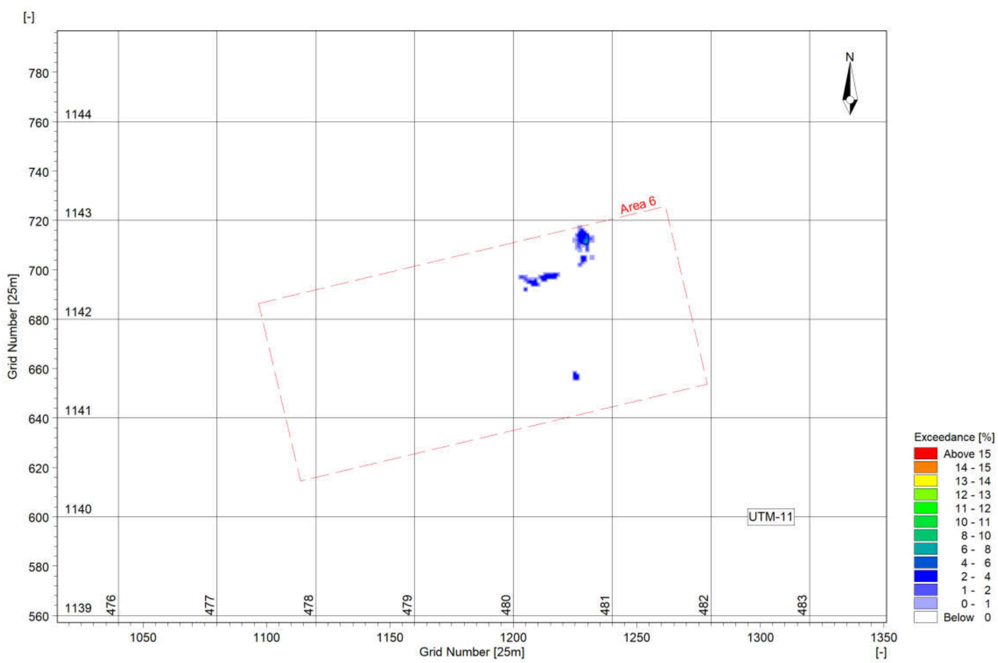

Figure 3.50 Scenario STR2b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

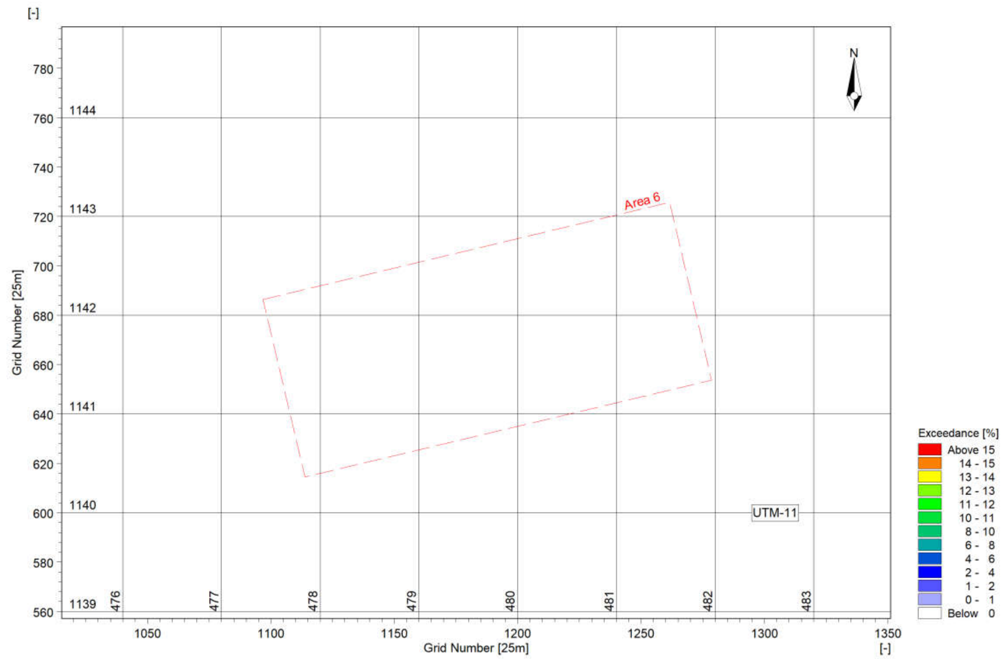

Figure 3.51 Scenario STR2b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

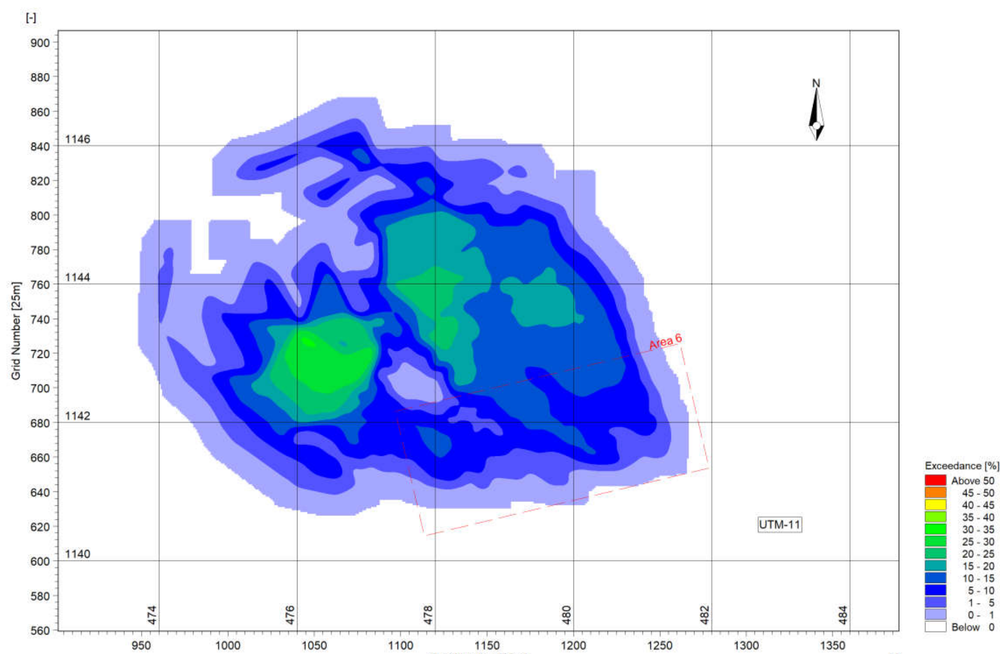

Figure 3.52 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

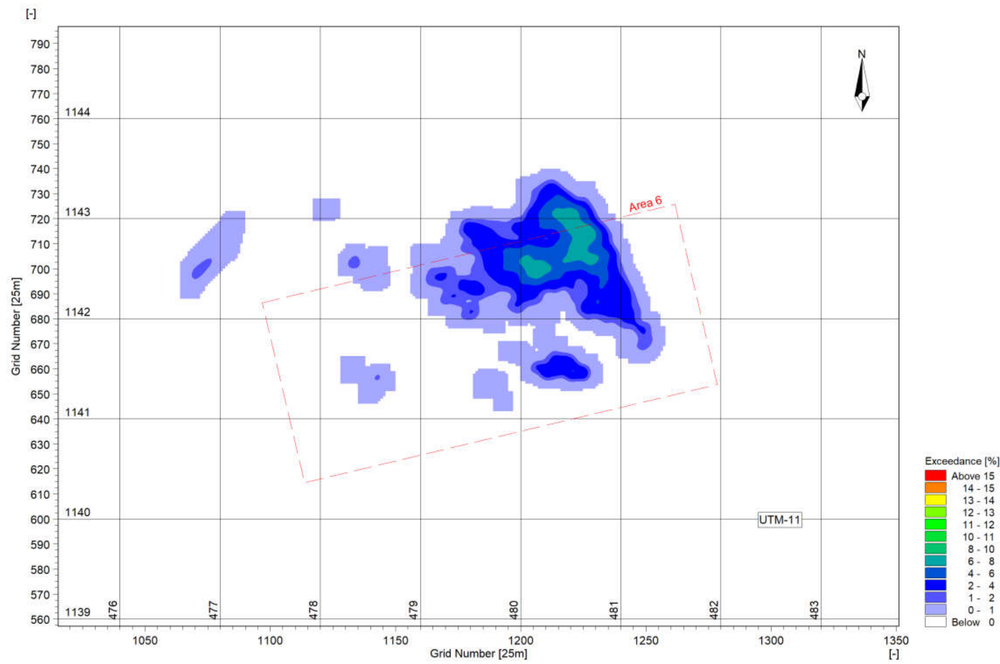

Figure 3.53 Scenario STR2b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

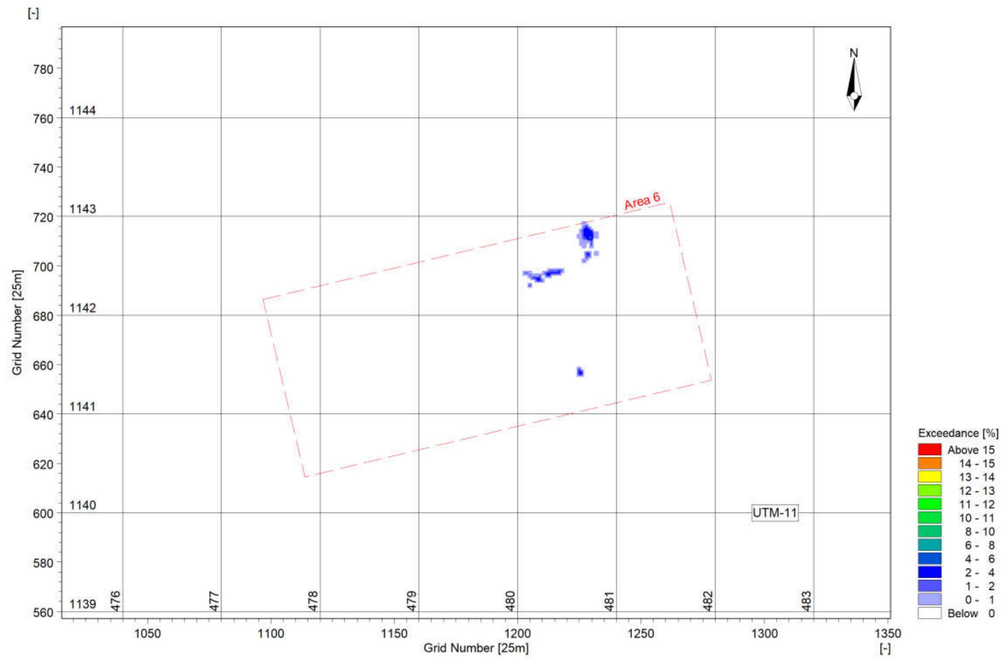

Figure 3.54 Scenario STR2b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

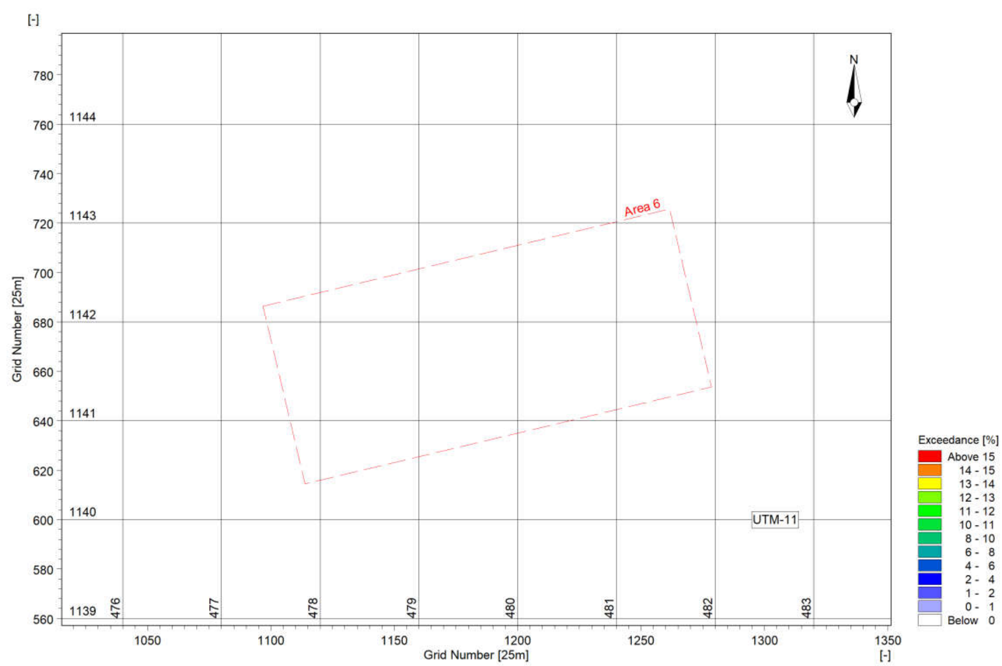

Figure 3.55 Scenario STR2b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.3.4 TSS at Mid-Water Column Discharge

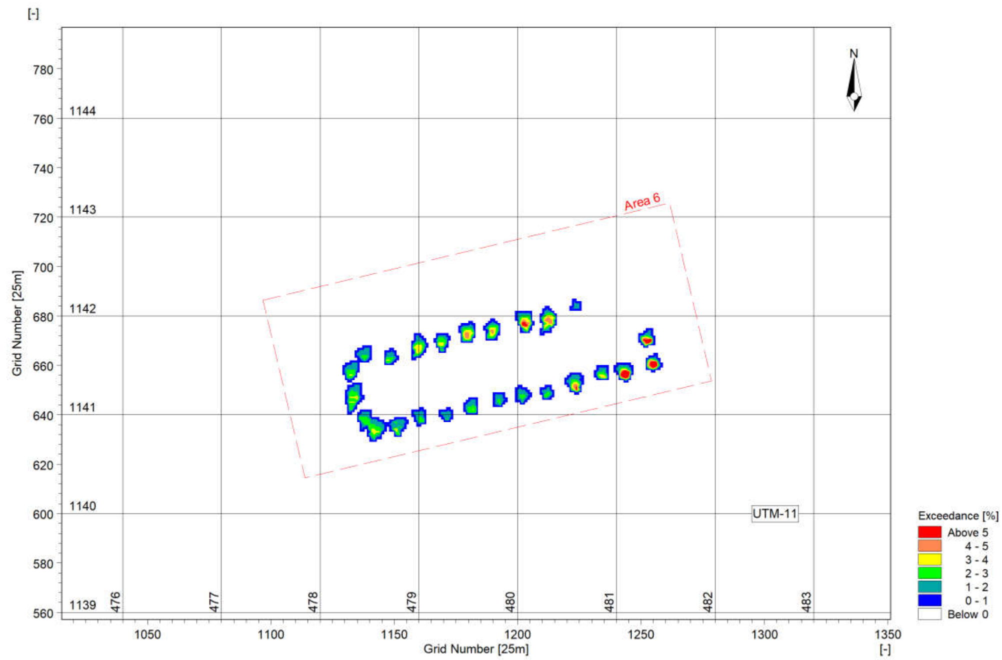

Figure 3.56 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

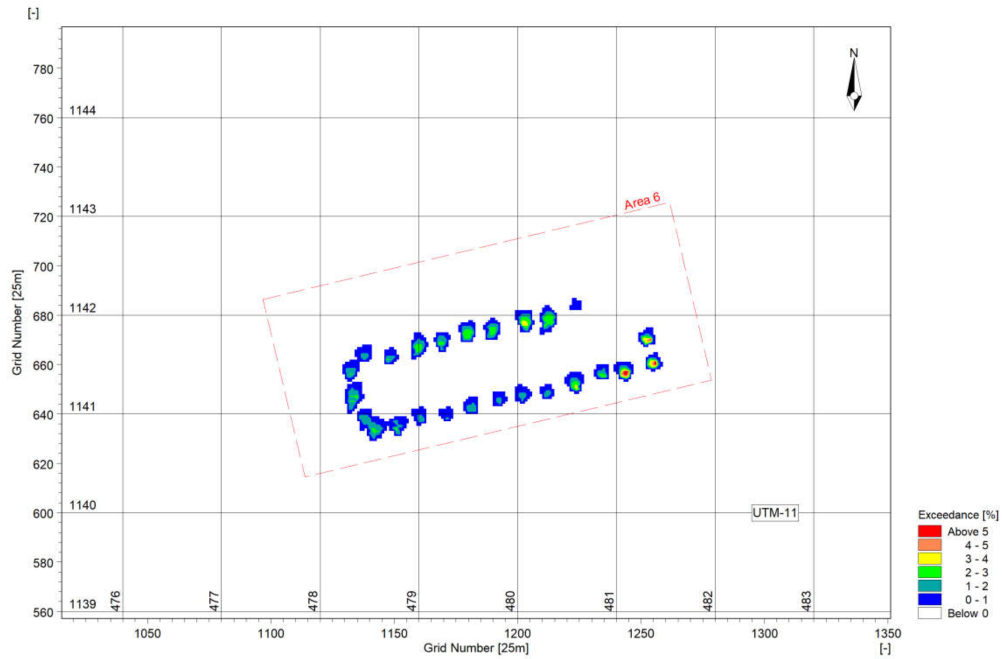

Figure 3.57 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

3.4 Scenario STR3a Results

Sedimentation results for Scenario STR3a are presented in Section 3.2.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.2.2, 20m above the seabed in Section 3.2.3 and at 1050m for the mid-water column discharge in Section 3.2.4.

3.4.1 Sedimentation

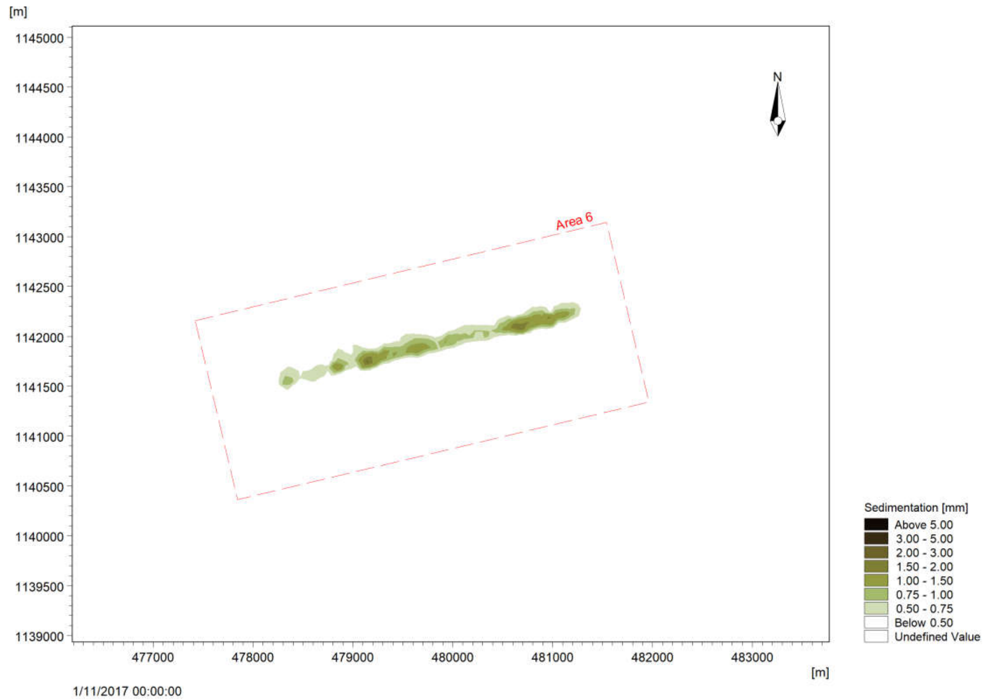

Figure 3.58 Scenario STR3a: Sedimentation (mm) at the final timestep

3.4.2 TSS 5m Above Seabed

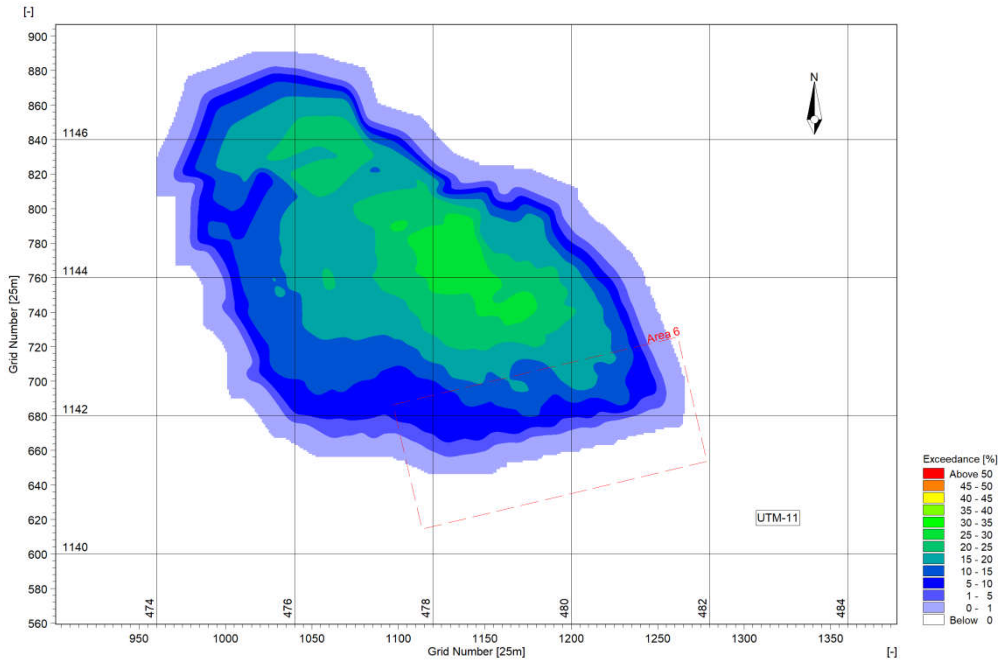

Figure 3.59 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

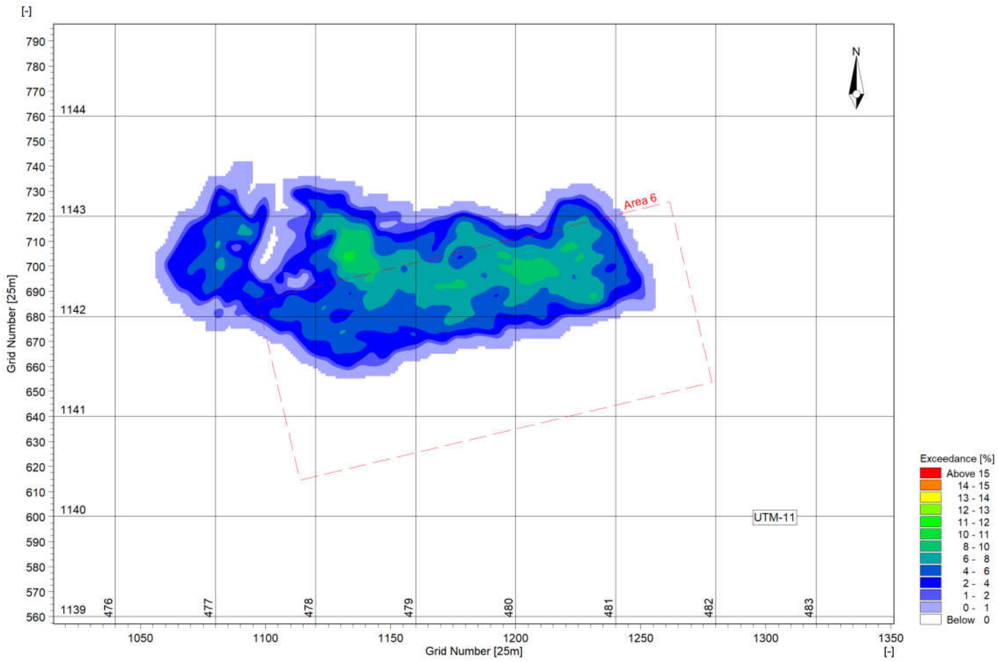

Figure 3.60 Scenario STR3a: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

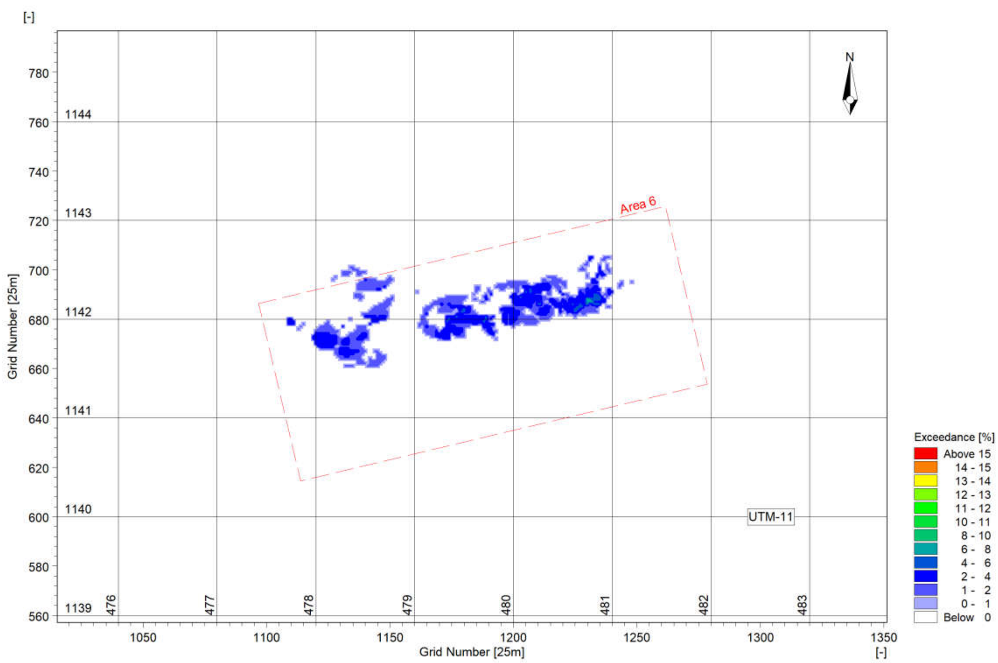

Figure 3.61 Scenario STR3a: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

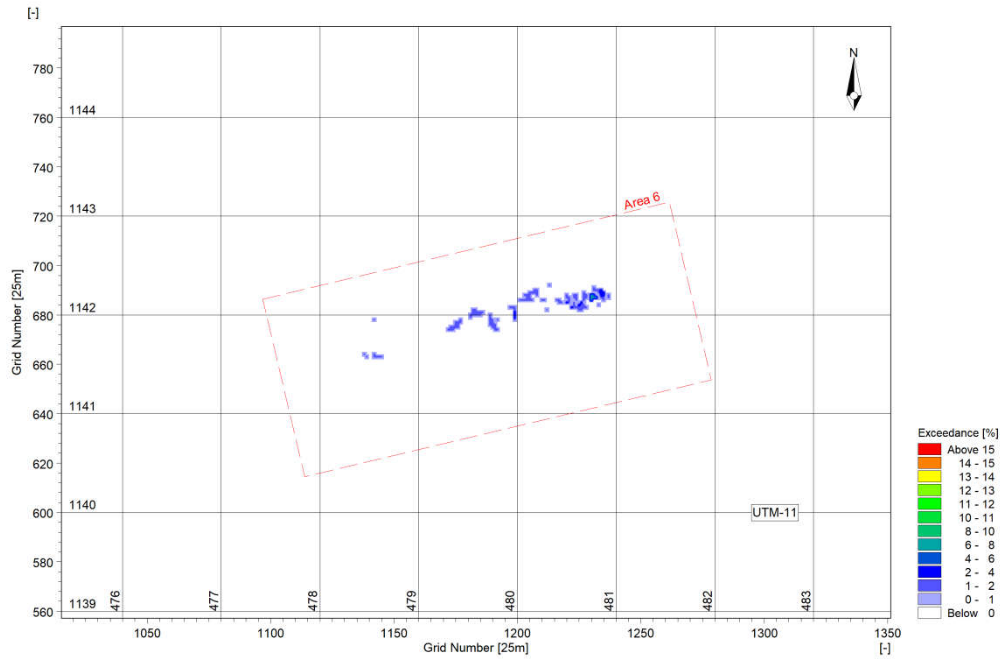

Figure 3.62 Scenario STR3a: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

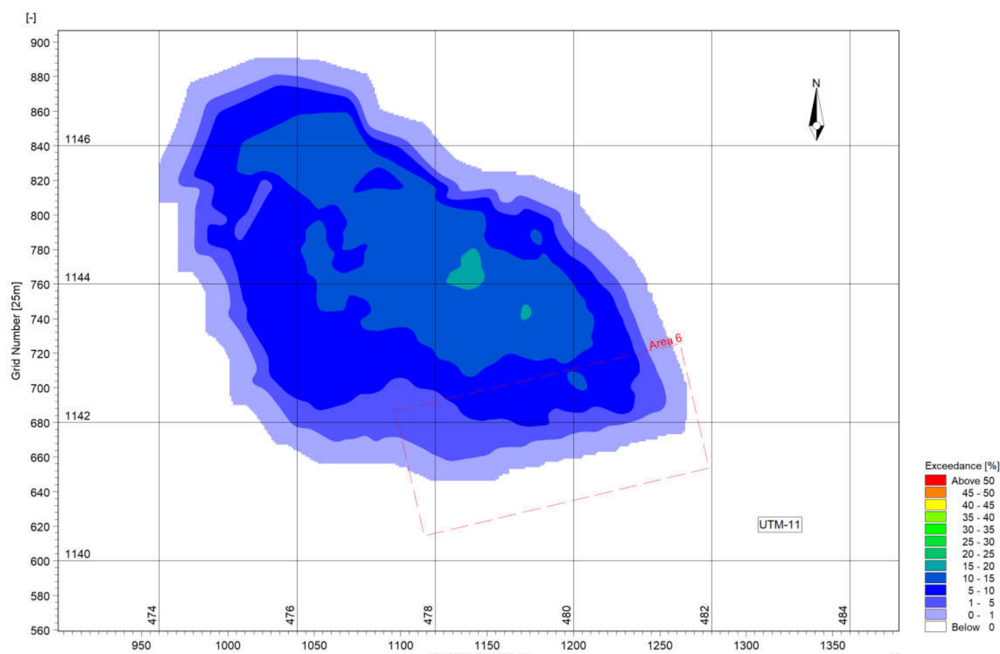

Figure 3.63 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

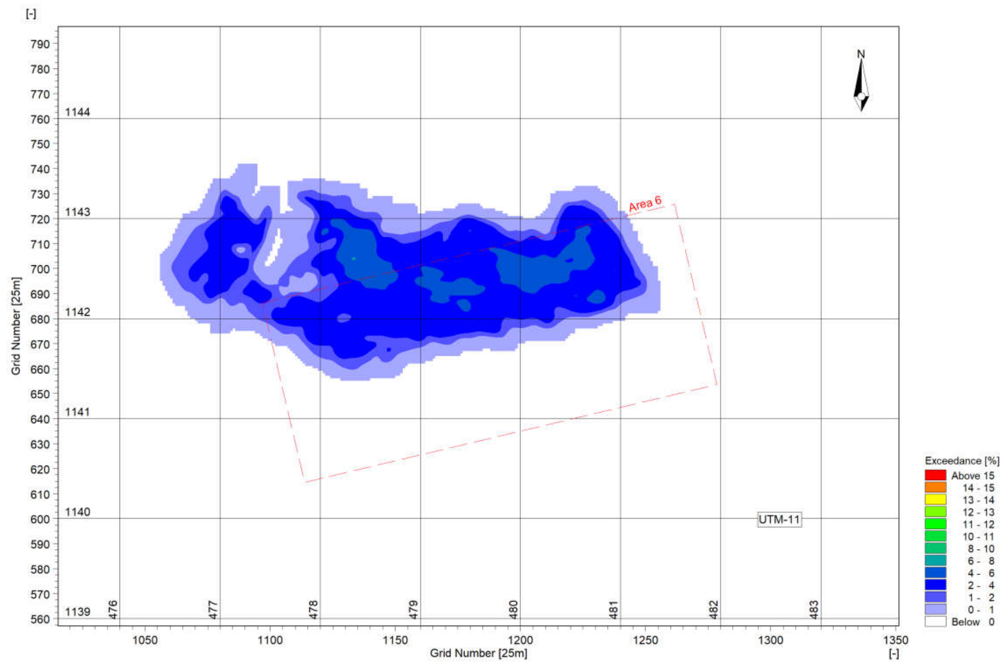

Figure 3.64 Scenario STR3a: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

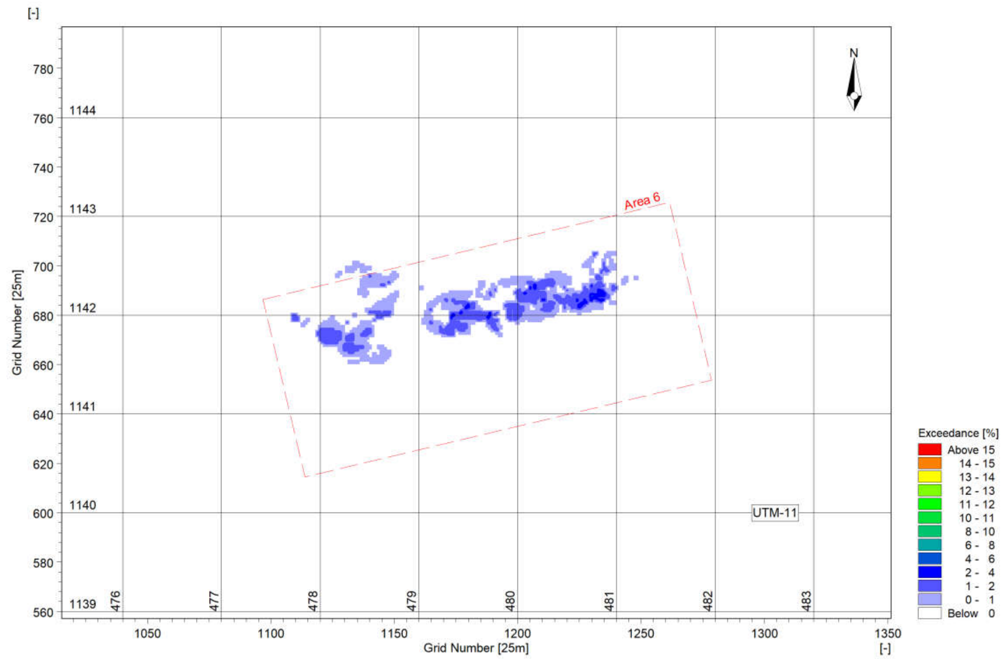

Figure 3.65 Scenario STR3a: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

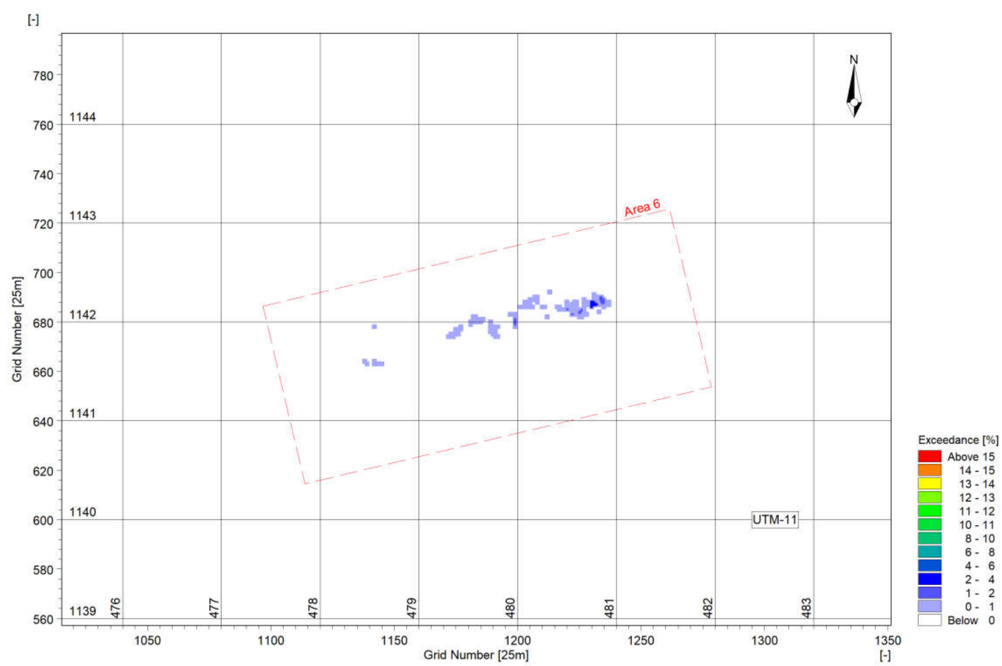

Figure 3.66 Scenario STR3a: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.4.3 TSS 20m Above Seabed

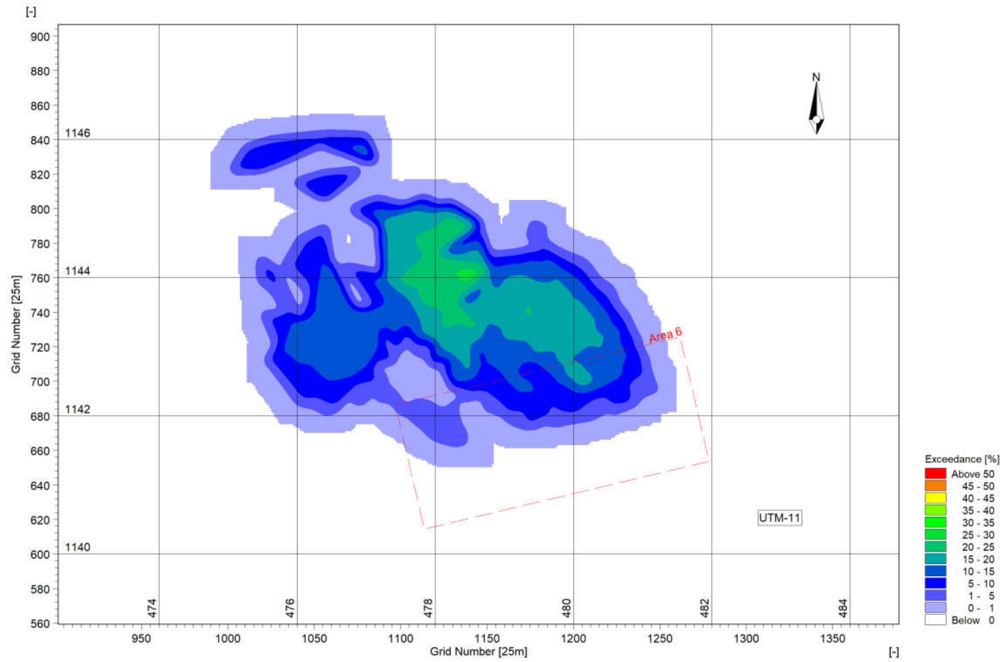

Figure 3.67 Scenario STR3a: Exceedance percentage of 0.1mg/l, 24 hours post-production at 20m above the seabed

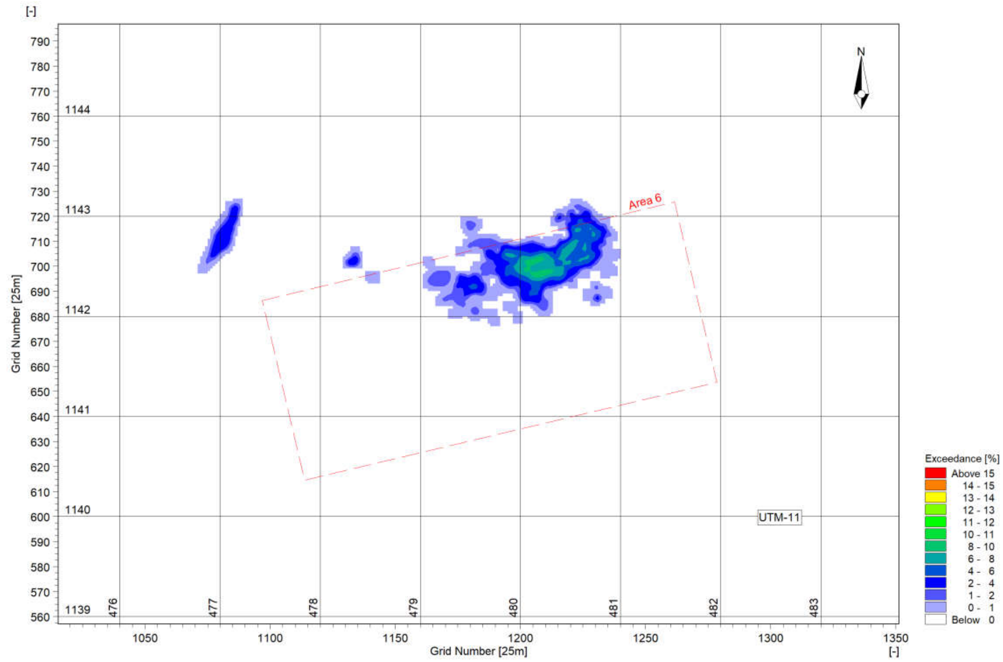

Figure 3.68 Scenario STR3a: Exceedance percentage of 1mg/l, 24 hours post-production at 20m above the seabed

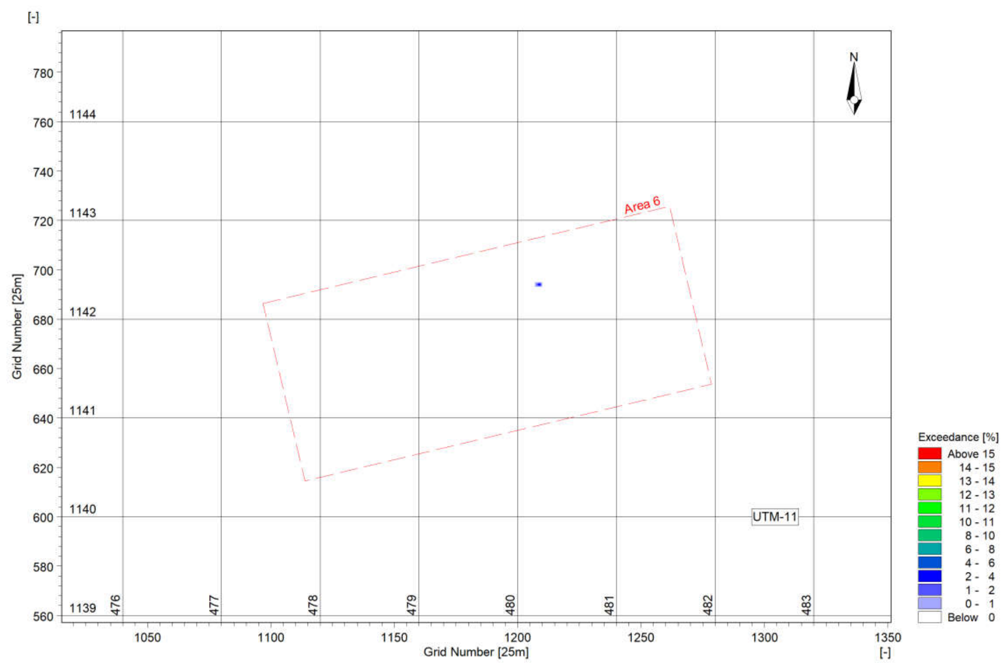

Figure 3.69 Scenario STR3a: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

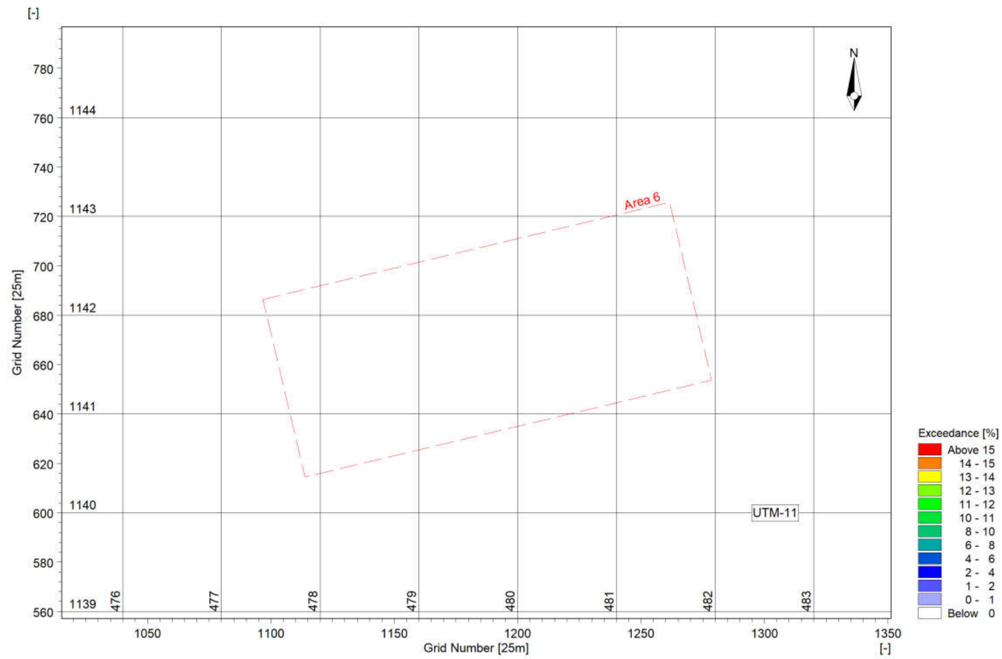

Figure 3.70 Scenario STR3a: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

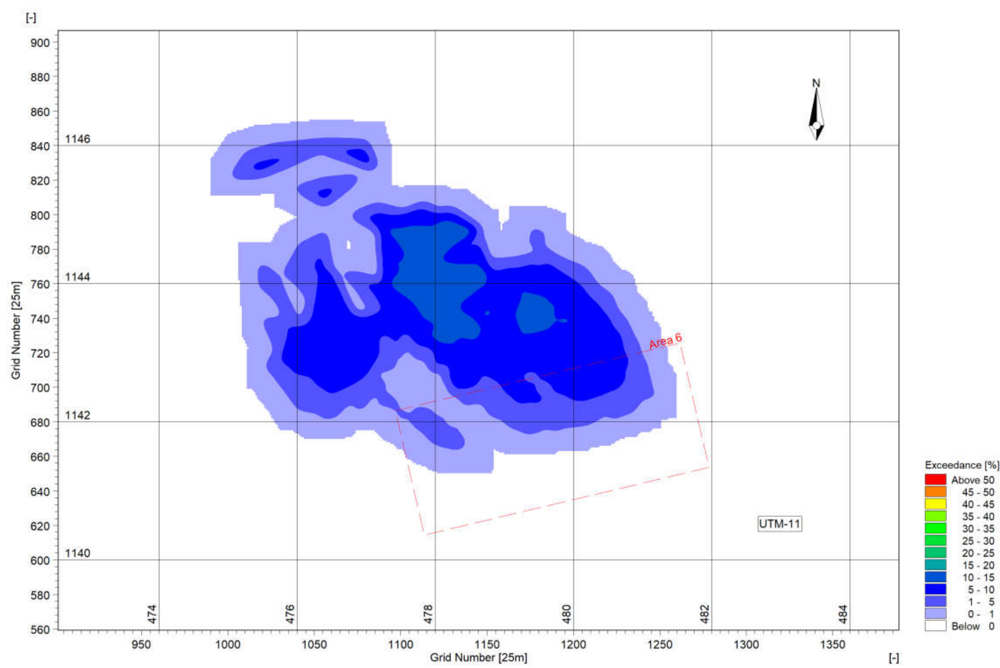

Figure 3.71 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

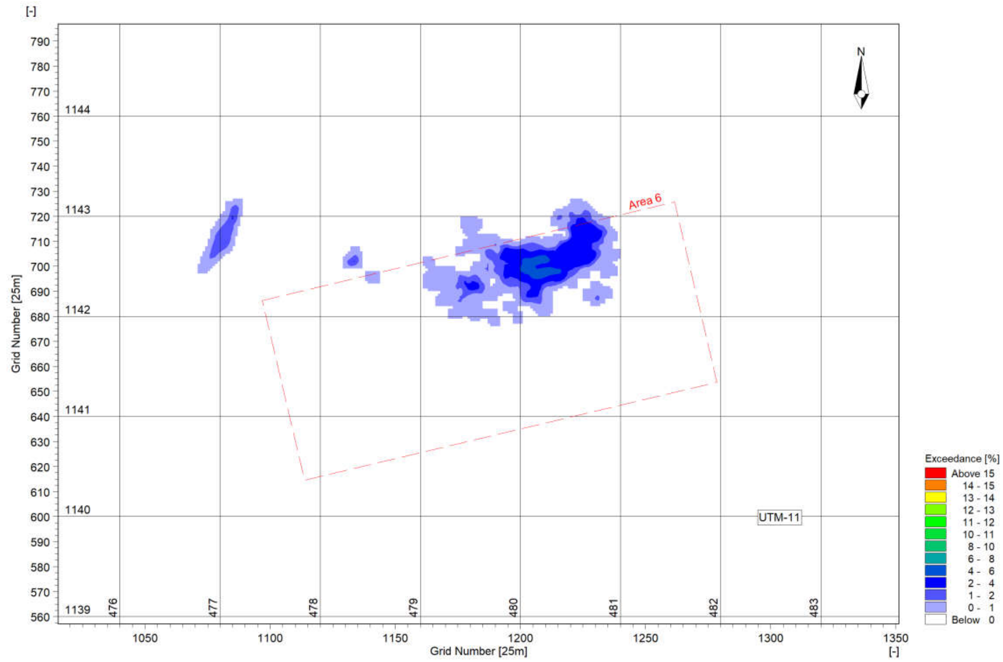

Figure 3.72 Scenario STR3a: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

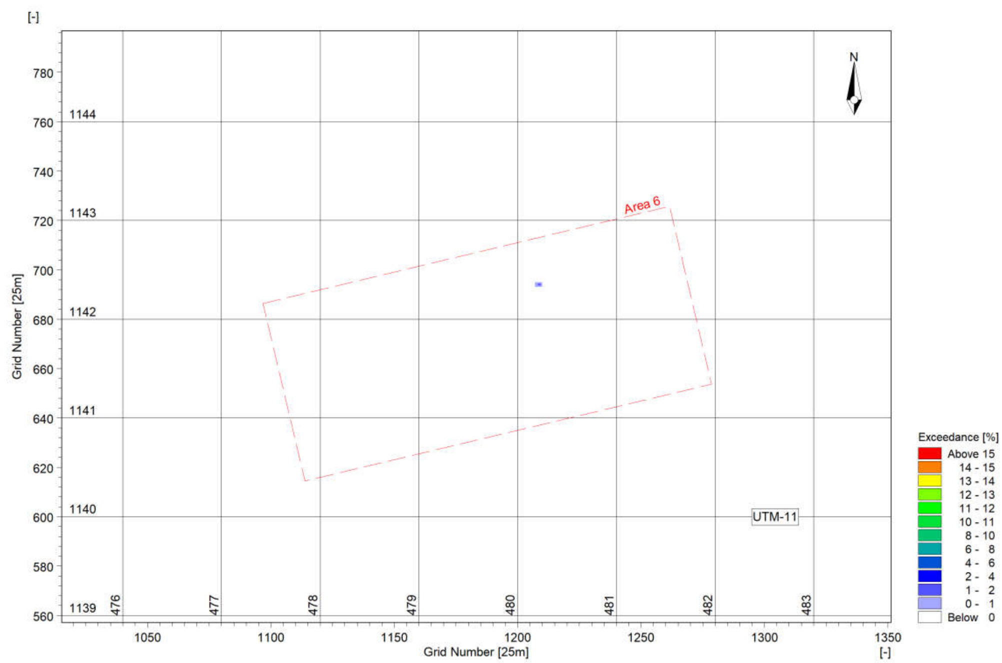

Figure 3.73 Scenario STR3a: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

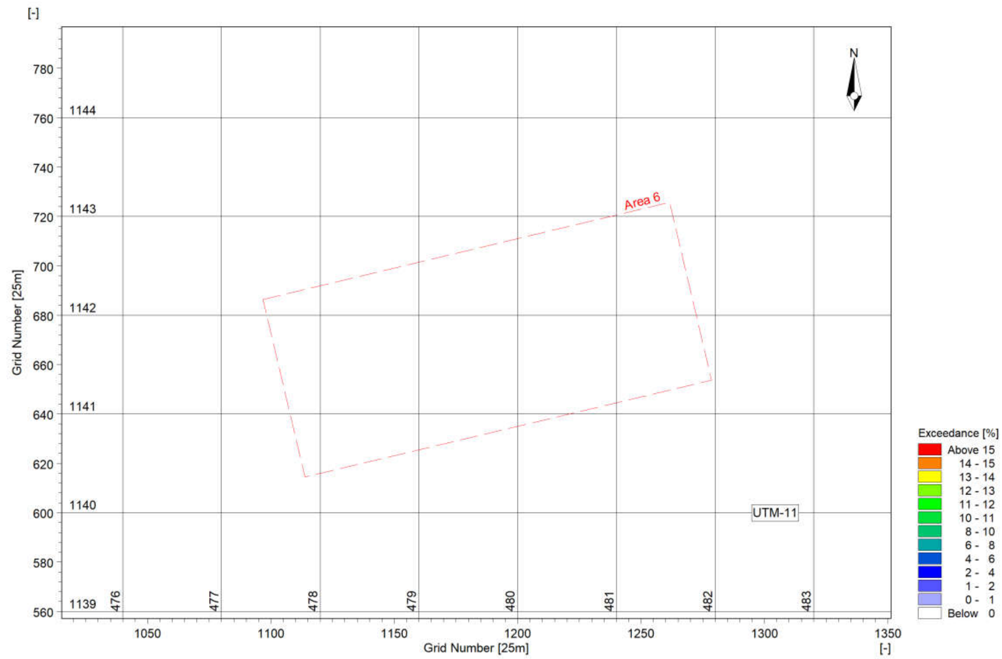

Figure 3.74 Scenario STR3a: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.4.4 TSS at Mid-Water Column Discharge

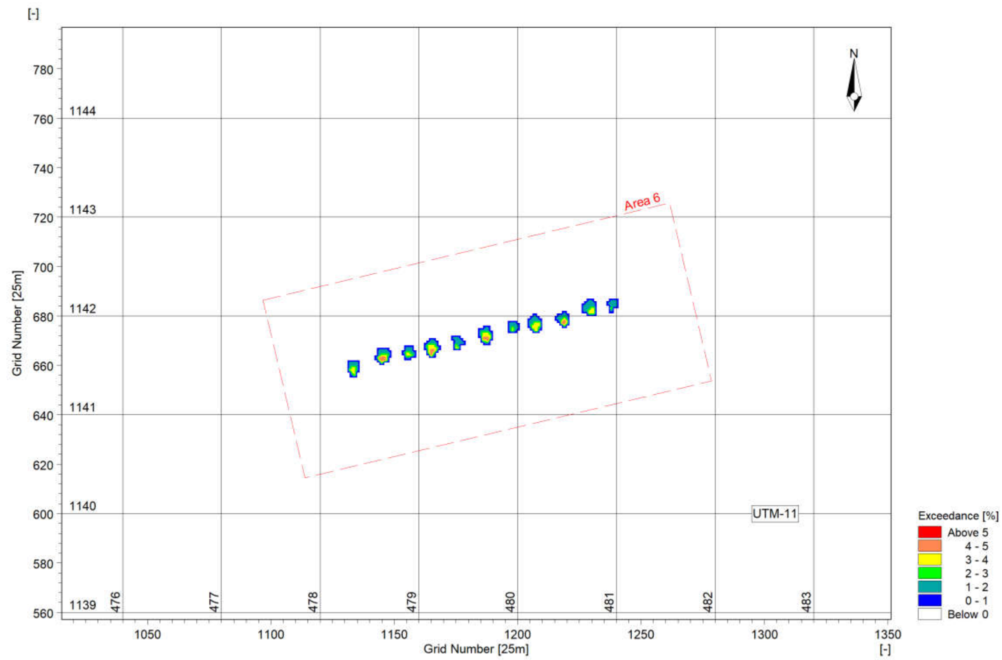

Figure 3.75 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

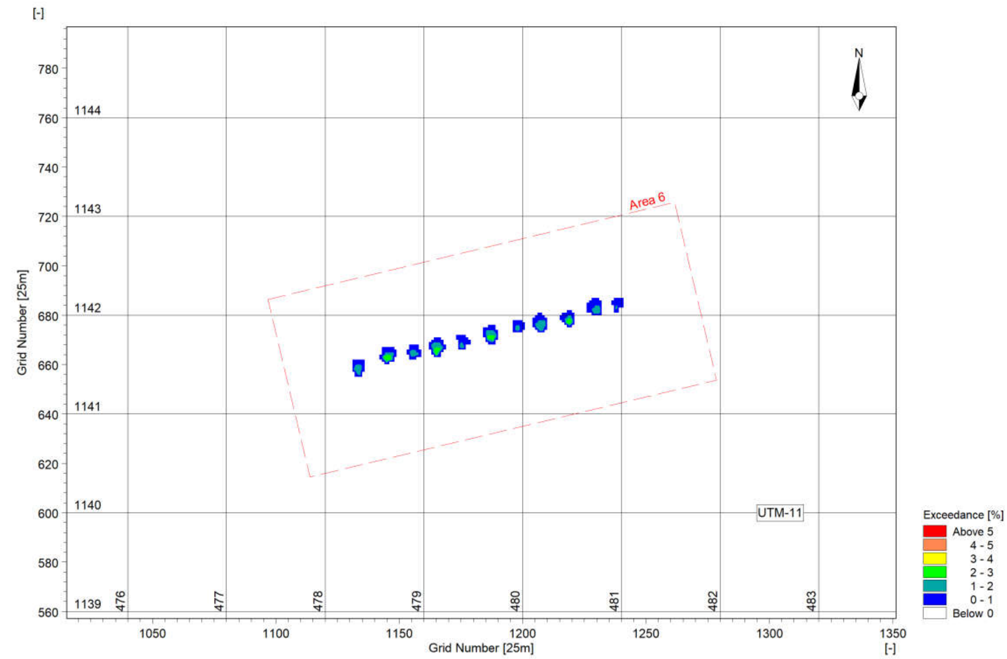

Figure 3.76 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

3.5 Scenario STR3b Results

Sedimentation results for Scenario STR3b are presented in Section 3.5.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.5.2, 20m above the seabed in Section 3.5.3 and at 1050m for the mid-water column discharge in Section 3.5.4.

3.5.1 Sedimentation

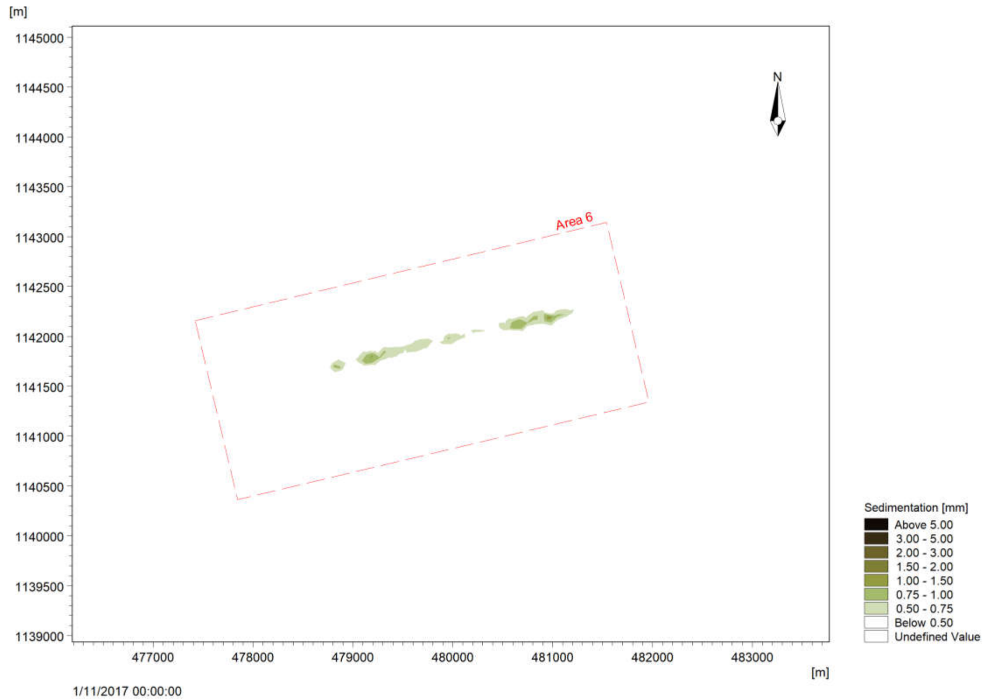

Figure 3.77 Scenario STR3b: Sedimentation (mm) at the final timestep

3.5.2 TSS 5m Above Seabed

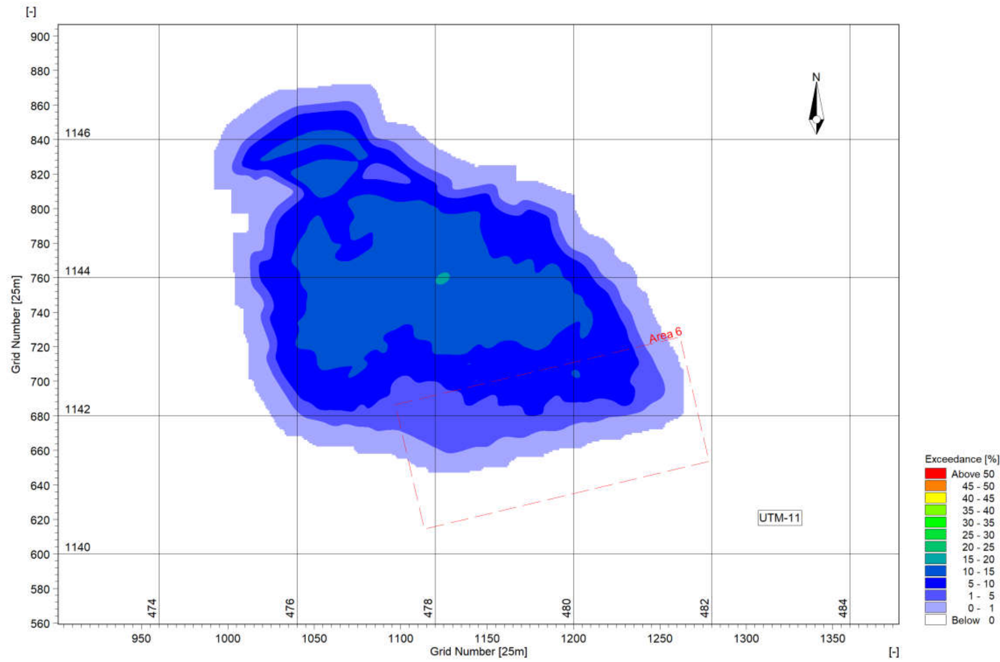

Figure 3.78 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

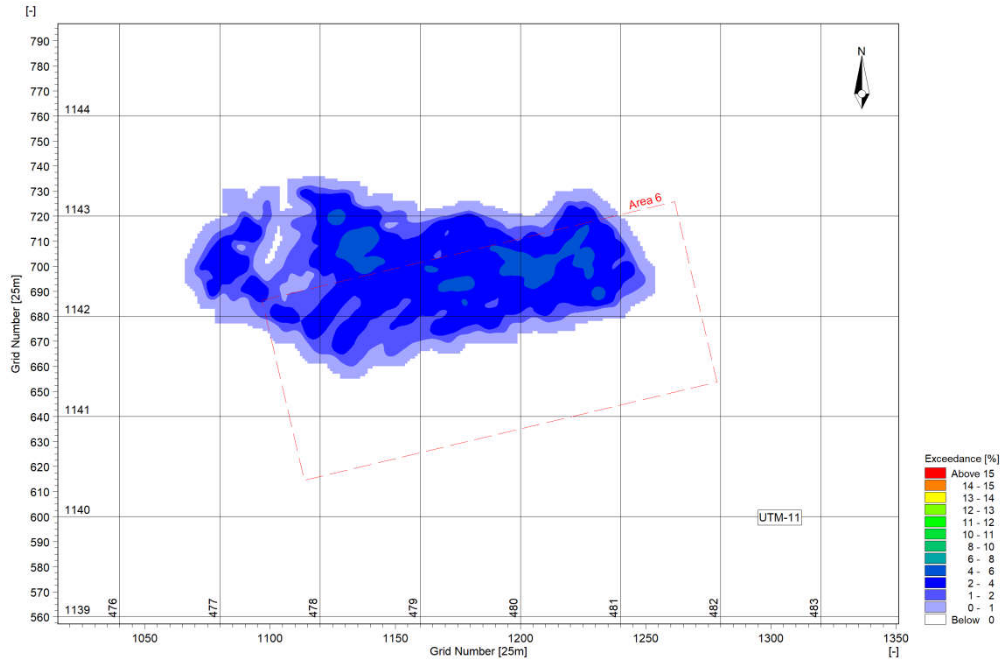

Figure 3.79 Scenario STR3b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

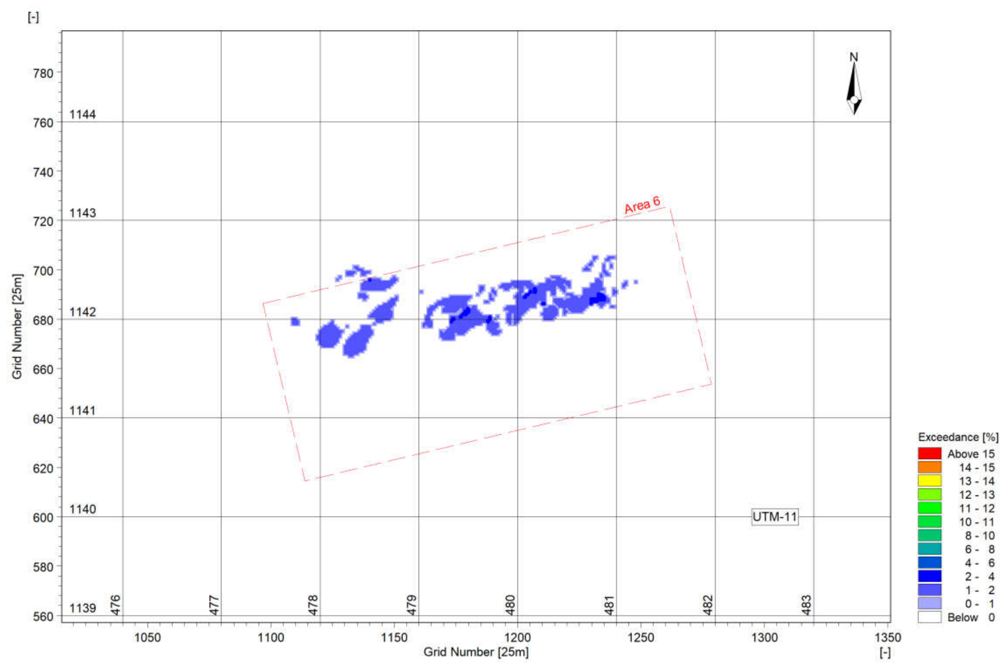

Figure 3.80 Scenario STR3b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

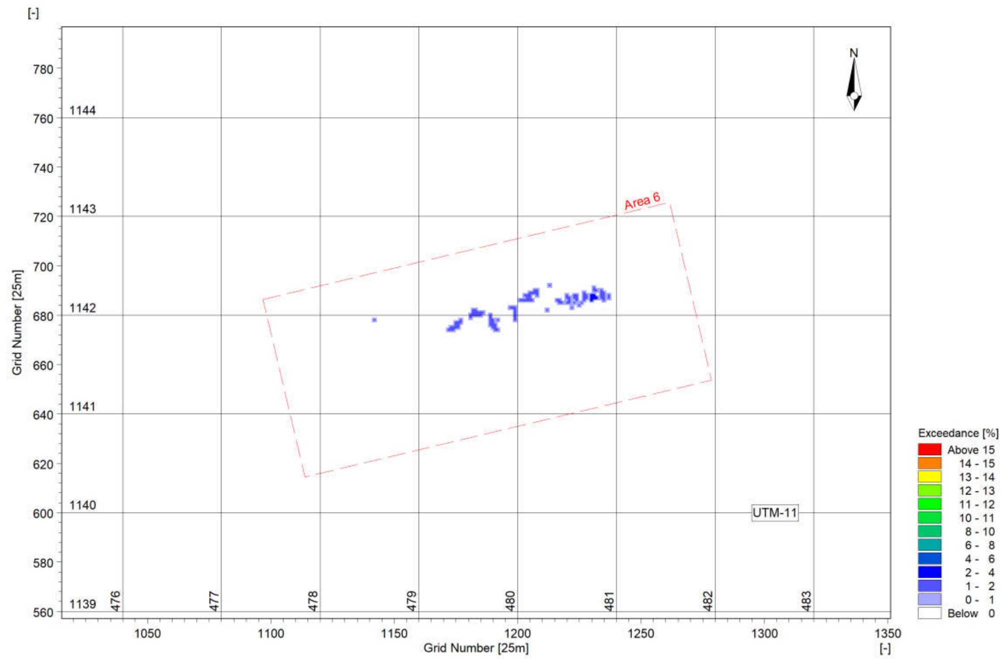

Figure 3.81 Scenario STR3b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

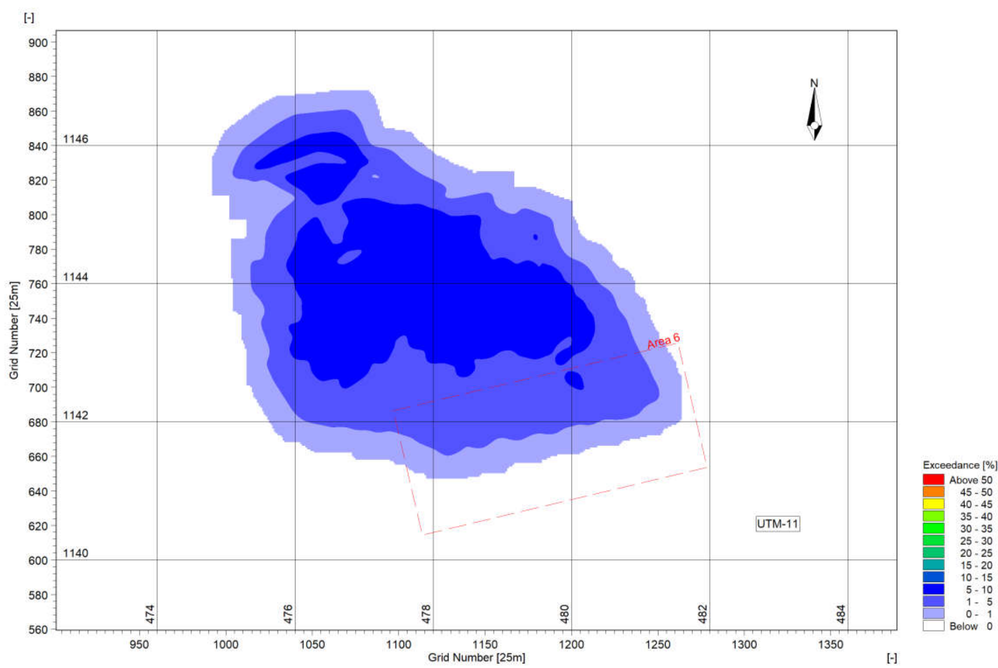

Figure 3.82 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

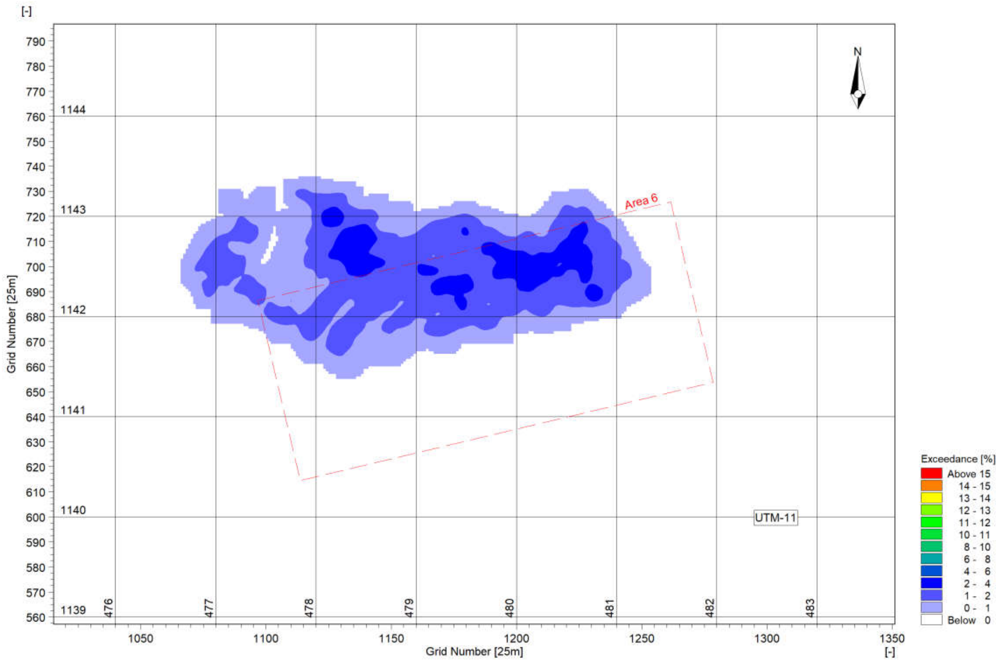

Figure 3.83 Scenario STR3b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

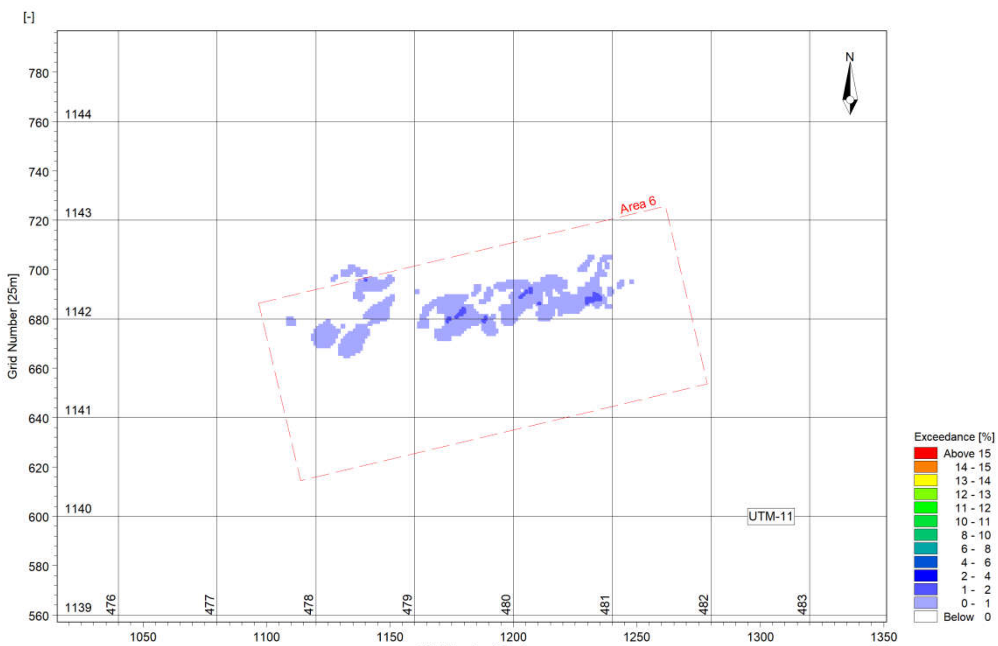

Figure 3.84 Scenario STR3b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

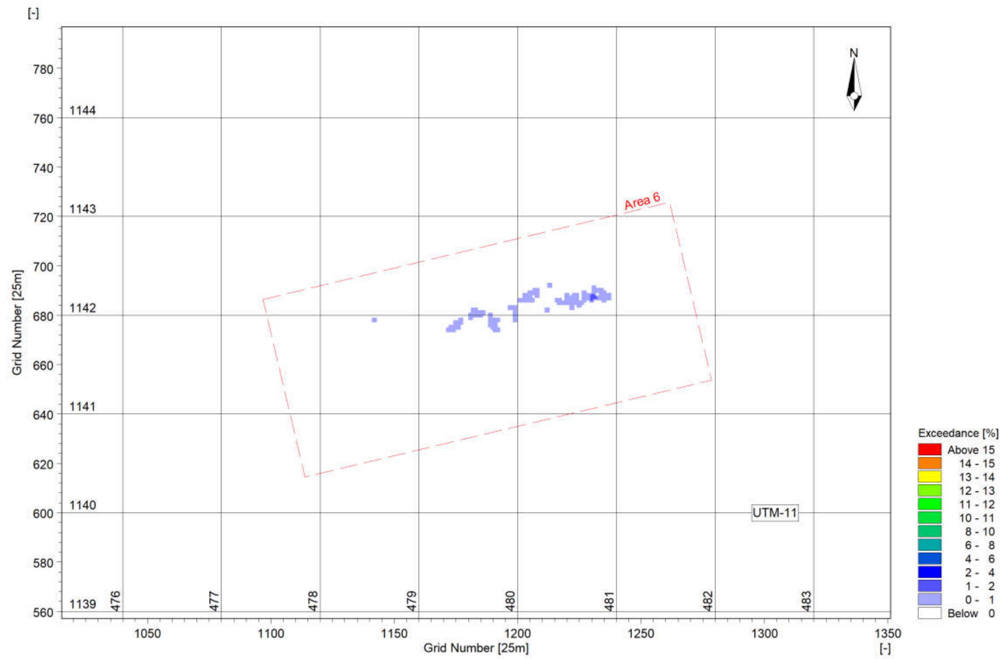

Figure 3.85 Scenario STR3b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.5.3 TSS 20m Above Seabed

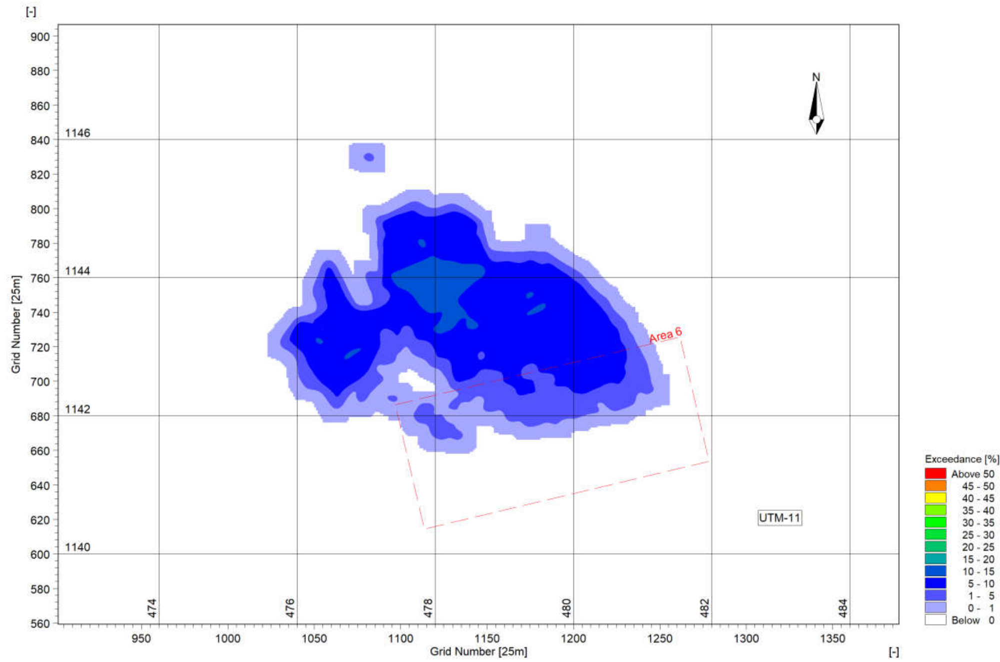

Figure 3.86 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

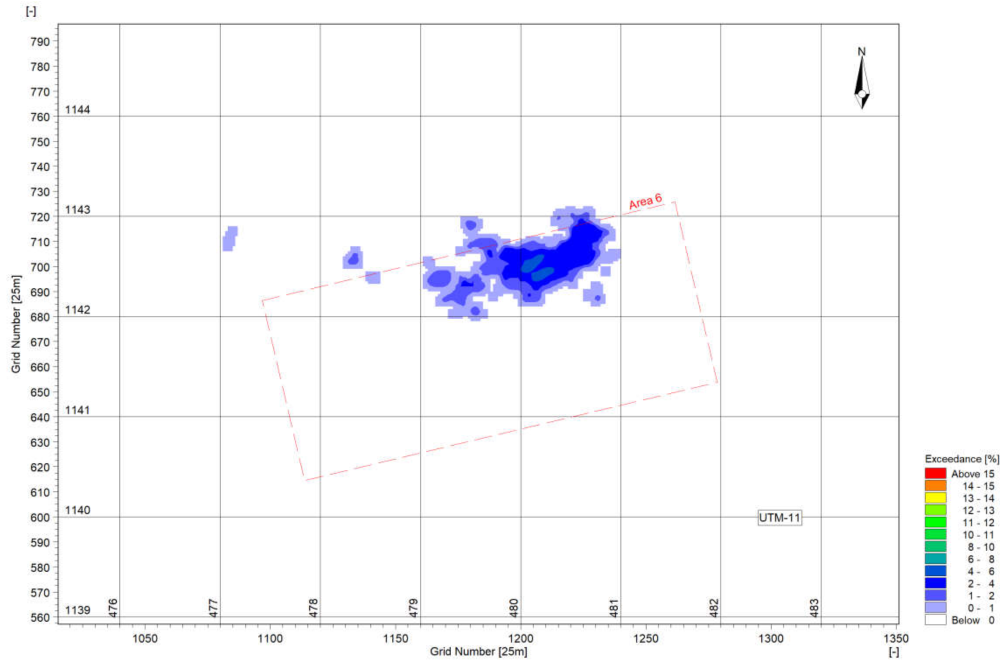

Figure 3.87 Scenario STR3b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

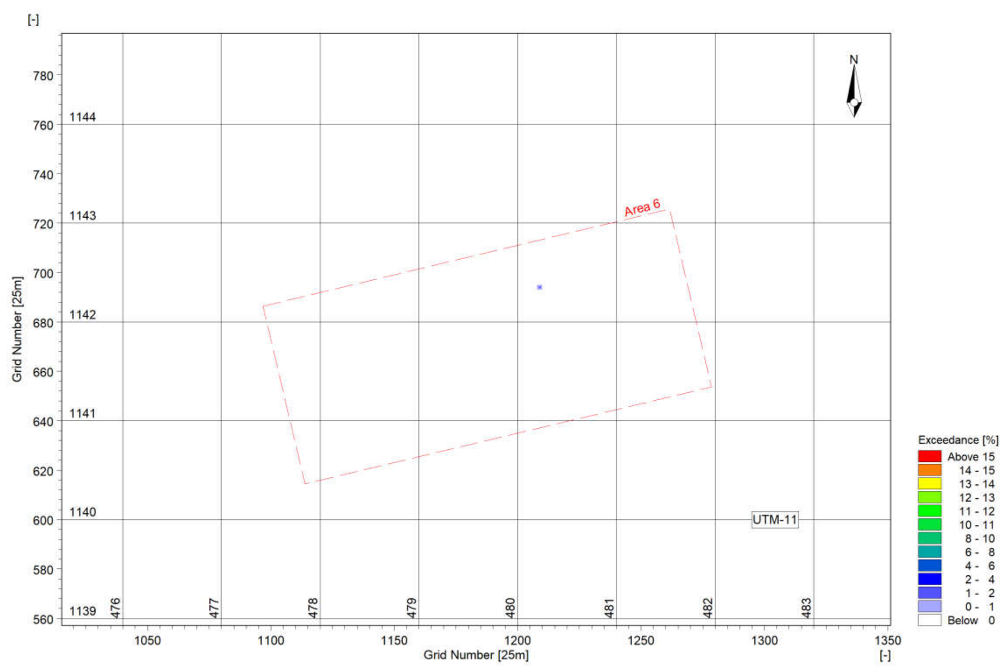

Figure 3.88 Scenario STR3b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

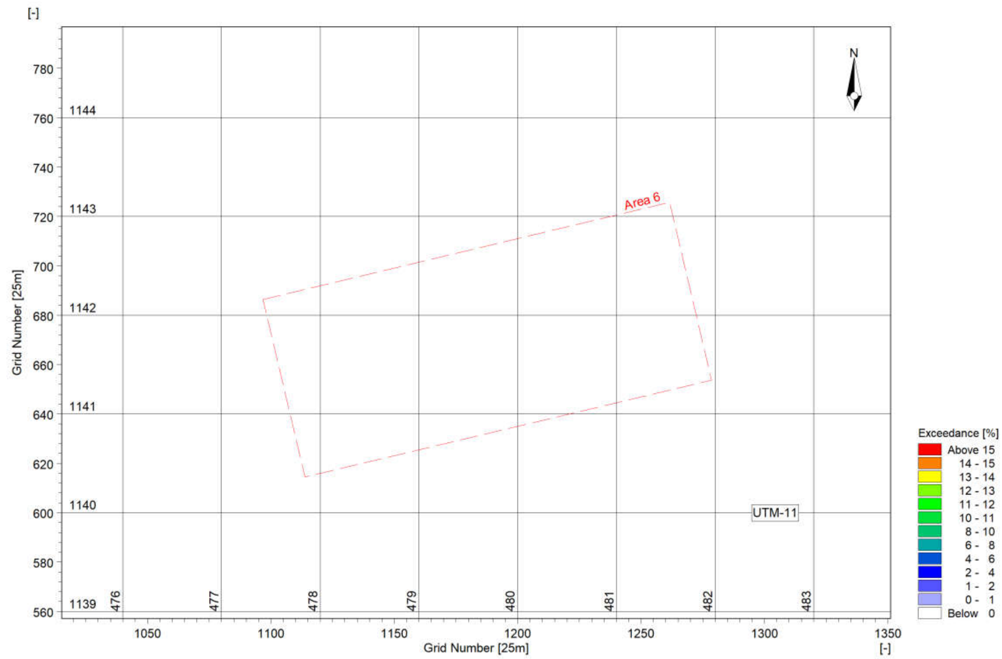

Figure 3.89 Scenario STR3b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

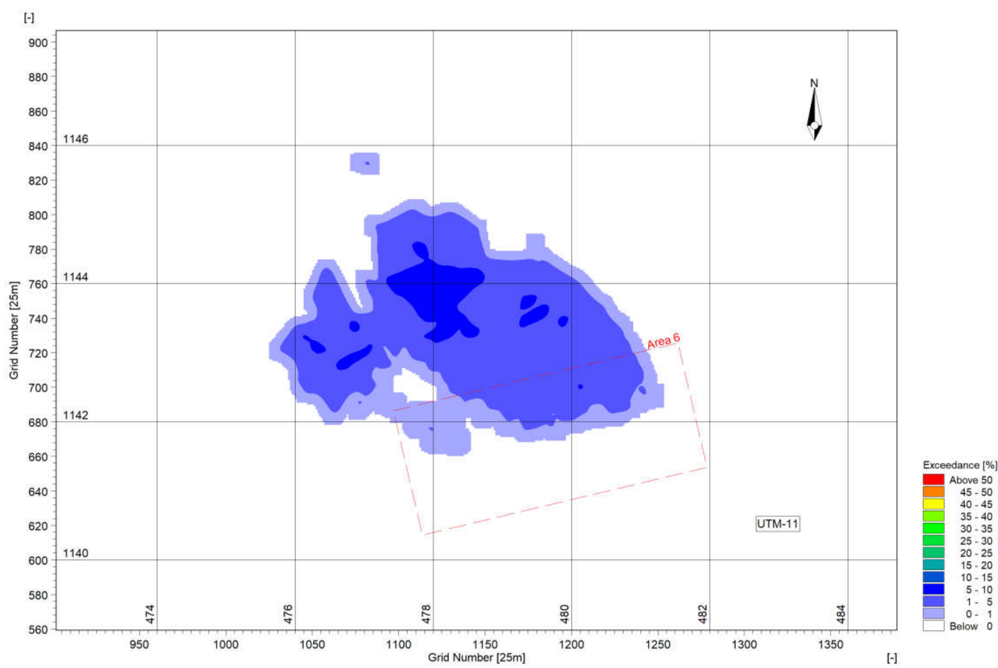

Figure 3.90 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

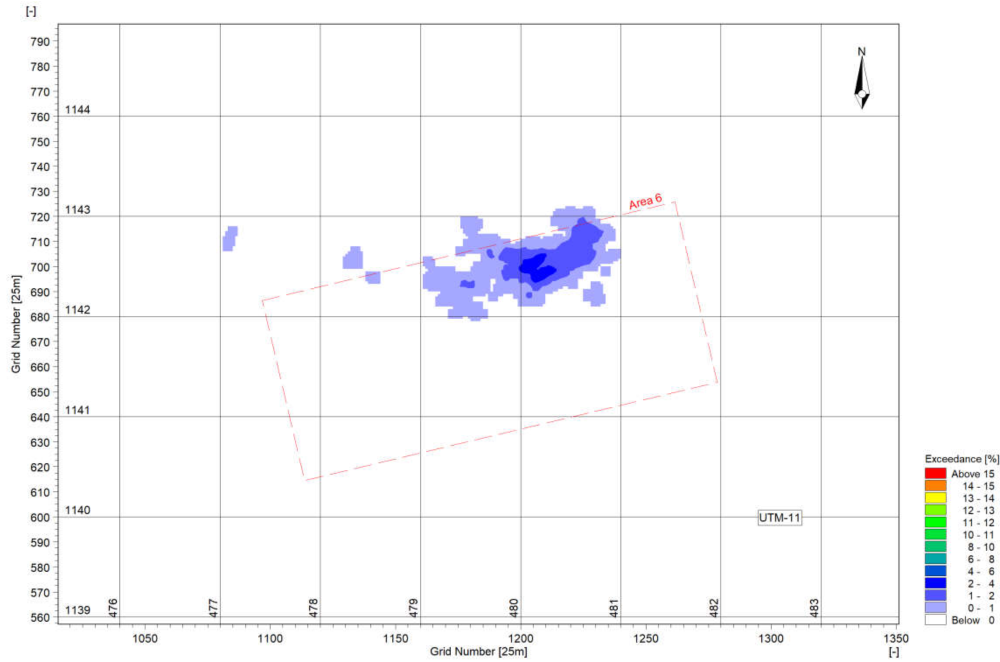

Figure 3.91 Scenario STR3b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

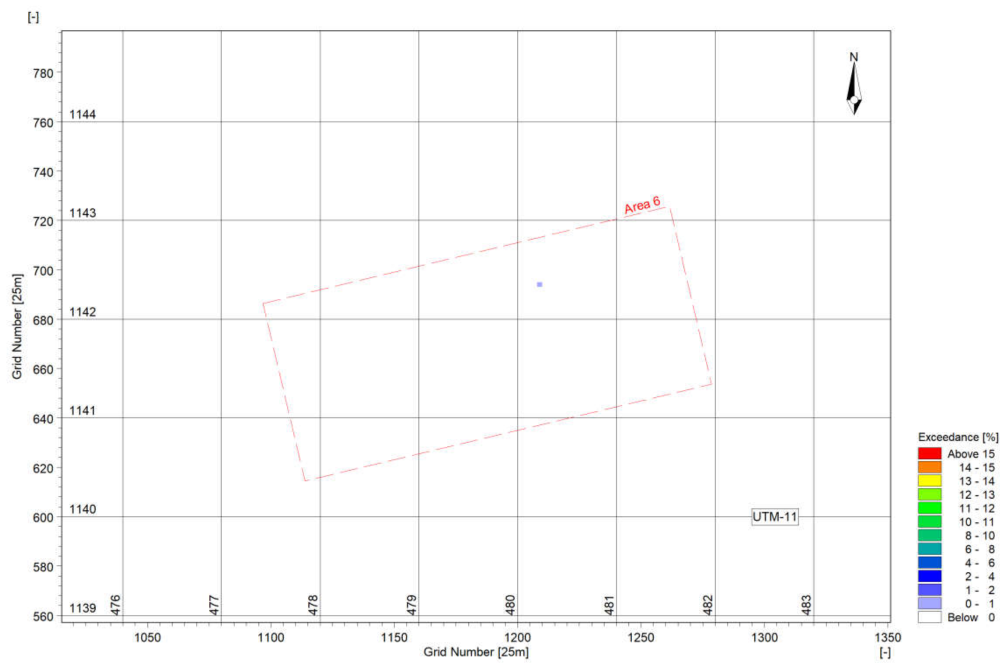

Figure 3.92 Scenario STR3b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

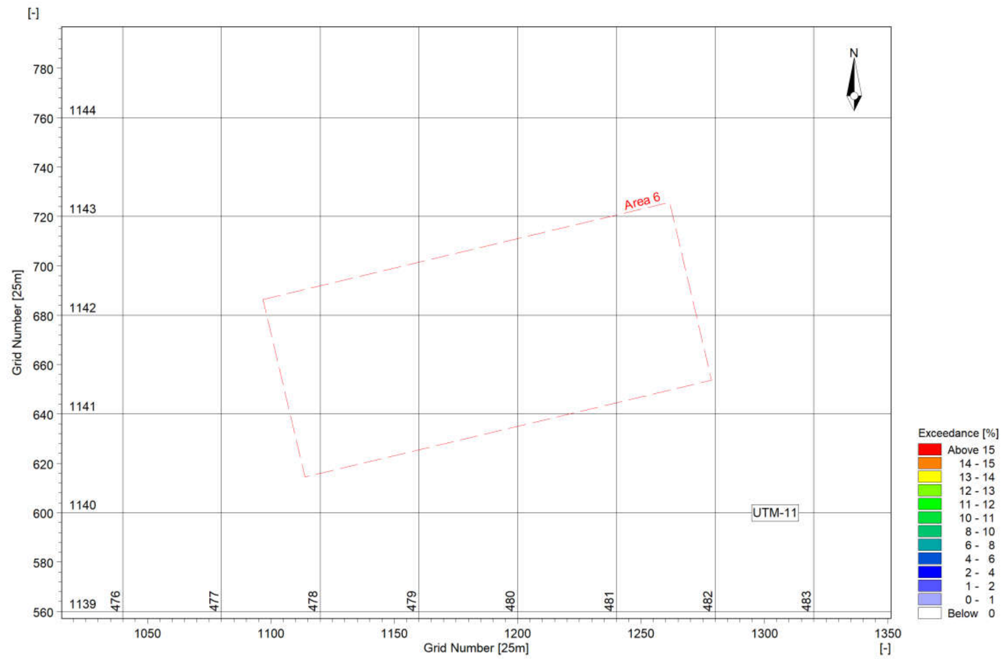

Figure 3.93 Scenario STR3b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.5.4 TSS at Mid-Water Column Discharge

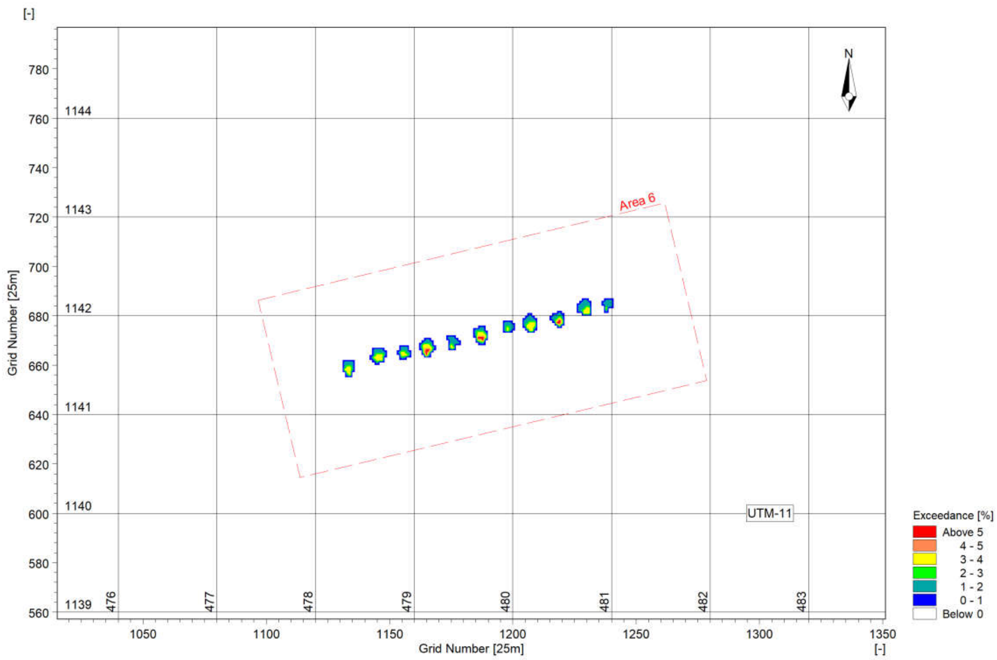

Figure 3.94 Scenario SR3b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

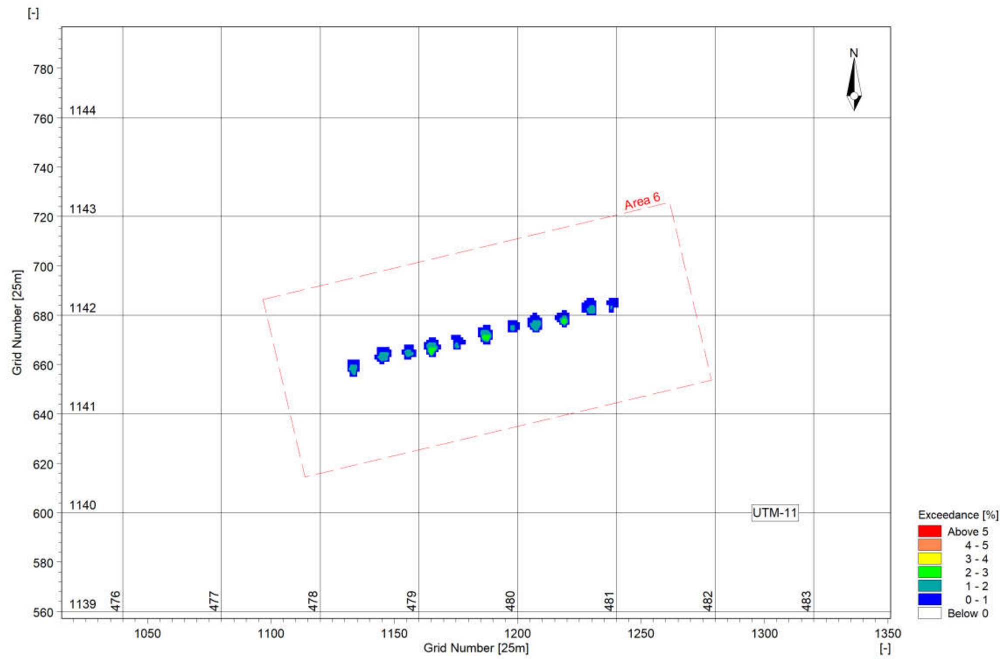

Figure 3.95 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

4 Cumulative Result of Pilot Collector Test Operation

The results presented in Section 3 represent the effect of the five individual pilot test operations that generate significant sediment spill. These five scenarios will be executed in sequence over a number of days, such that it is also important to consider the cumulative effect of these five scenarios on sedimentation and suspended sediment concentration.

4.1 Sedimentation

The relative location of the individual run lines may vary scenario to scenario in the field. To provide an indication of the sensitivity of the net sedimentation field to the specific offset of the individual test run lines, three sensitivity tests have been undertaken.

The base cumulative scenario is all tracks as per Section 2.3.5. Results for this base case are presented in Figure 4.1. For the two sensitivity tests, the centrelines of the tracks are offset as per Table 4.1, with positive offsets representing a northerly shift of the individual tracks and a negative offset, a southerly shift of the individual scenario tracks. Results for these two sensitivity tests are presented in Figure 4.2 and Figure 4.3.

Table 4-1 STR Track centreline offsets for cumulative sedimentation sensitivity testing

Cumulative Scenario	Offset (m) for each sensitivity test				
	STR1b	STR2a	STR2b	STR3a	STR3b
Base	0	0	0	0	0
Shift 1	-150	0	150	50	100
Shift 2	-300	0	300	100	200

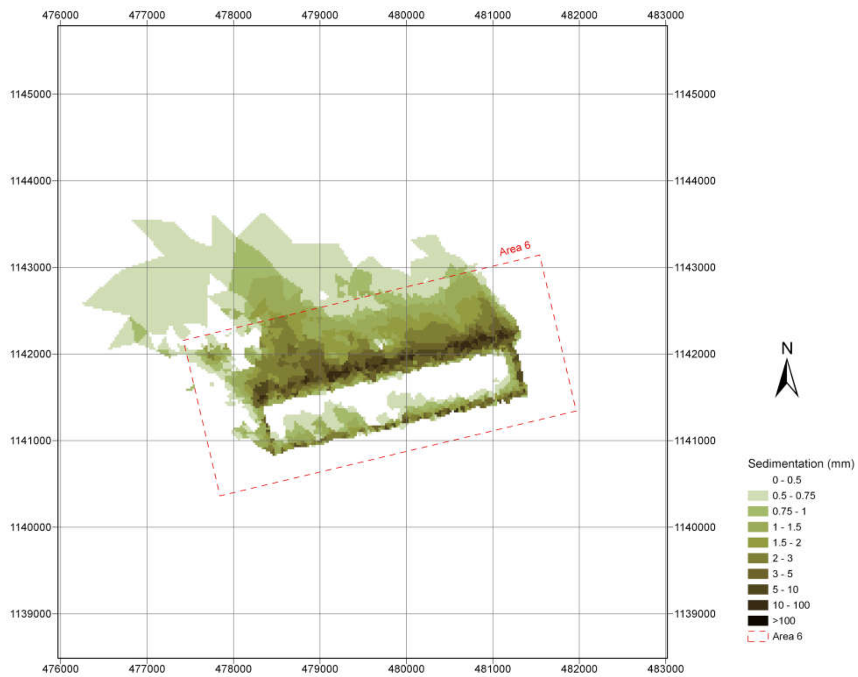

Figure 4.1 Cumulative sedimentation (mm) Base Case

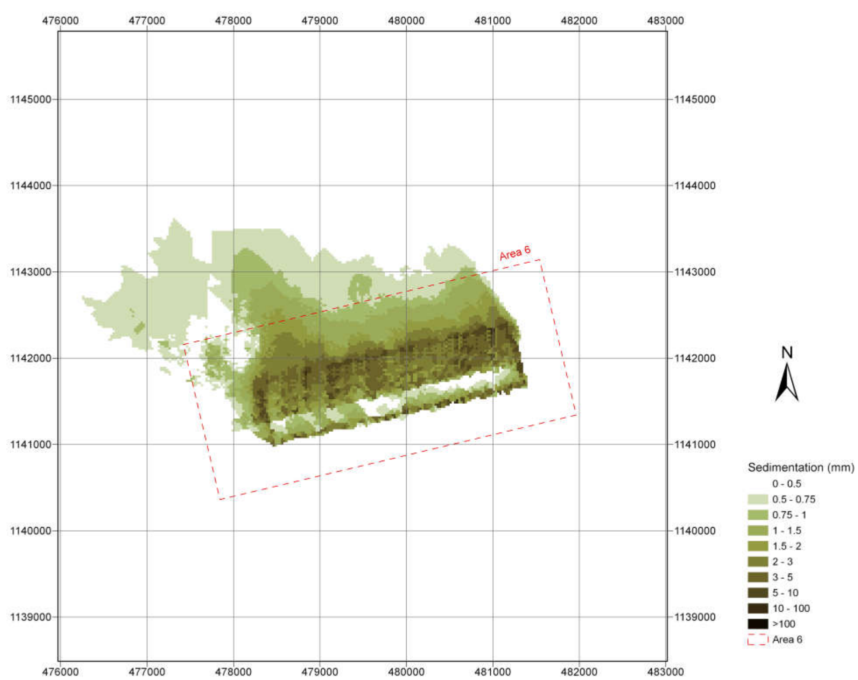

Figure 4.2 Cumulative sedimentation (mm) Sensitivity Test Shift 1

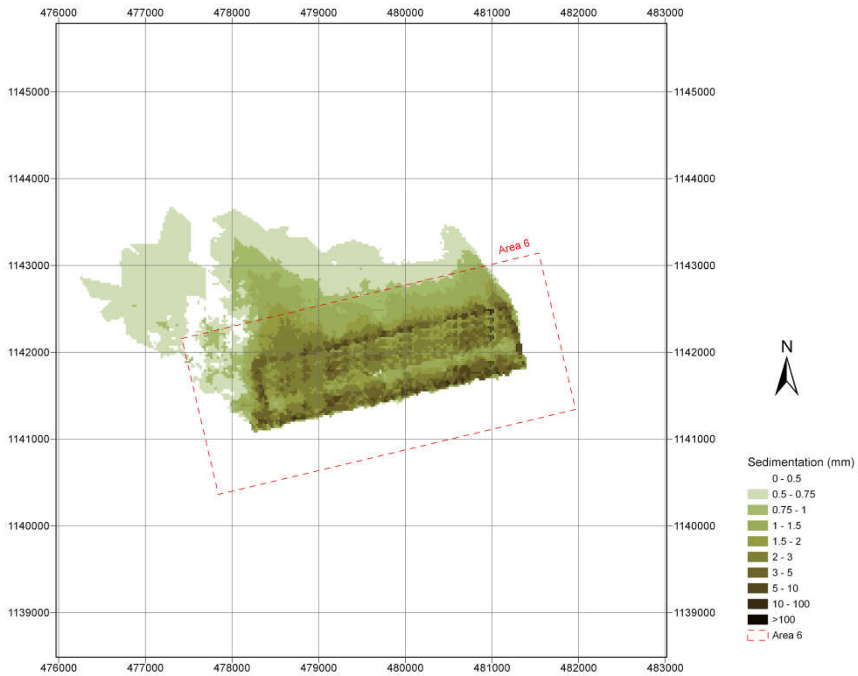

Figure 4.3 Cumulative sedimentation (mm) Sensitivity Test Shift 2

4.2 Suspended Sediments

For the cumulative total suspended sediment concentrations, the specific timing of the individual pilot tests activities is more important than the relative location of the tracks (within the limits addressed in Table 4.1). Allseas have provided an estimate of the sequence and likely timing of the five pilot test activities generating significant sediment spill as documented in Table 4.2.

Cumulative Exceedance of threshold concentrations 5m above the seabed and presented in Section 4.2.1, 20m above the seabed in Section 4.2.2 and at 1050m for the mid-water column discharge in Section 4.2.3. Summary statistics are provided in Section 4.2.4.

Table 4-2 STR sequence and start time offset for cumulative suspended sediment assessment

STR Order	Total test time Per STR	STR start time shift from previous STR start
1b	95hrs	0
2a	41hrs	95hrs
2b	61hrs	41hrs
3a	29hrs	61hrs
3b	33hrs	29hrs

4.2.1 TSS 5m Above Seabed

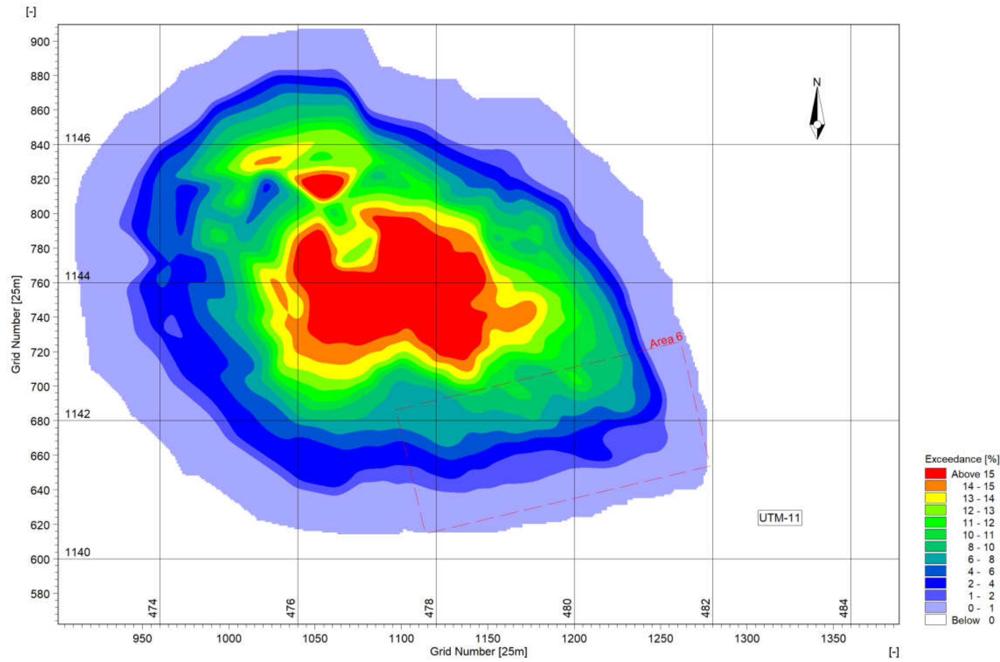

Figure 4.4 Net exceedance percentage of 0.1mg/l at 5m above the seabed from start of STR1b to 24hrs after completion of STR3b

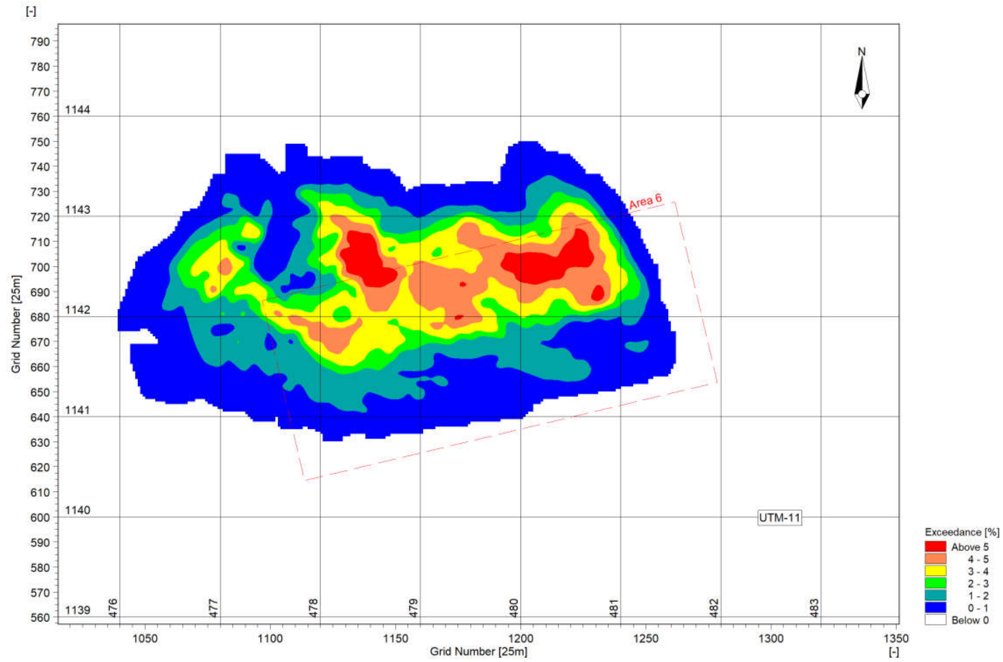

Figure 4.5 Net exceedance percentage of 1mg/l at 5m above the seabed from start of STR1b to 24hrs after completion of STR3b

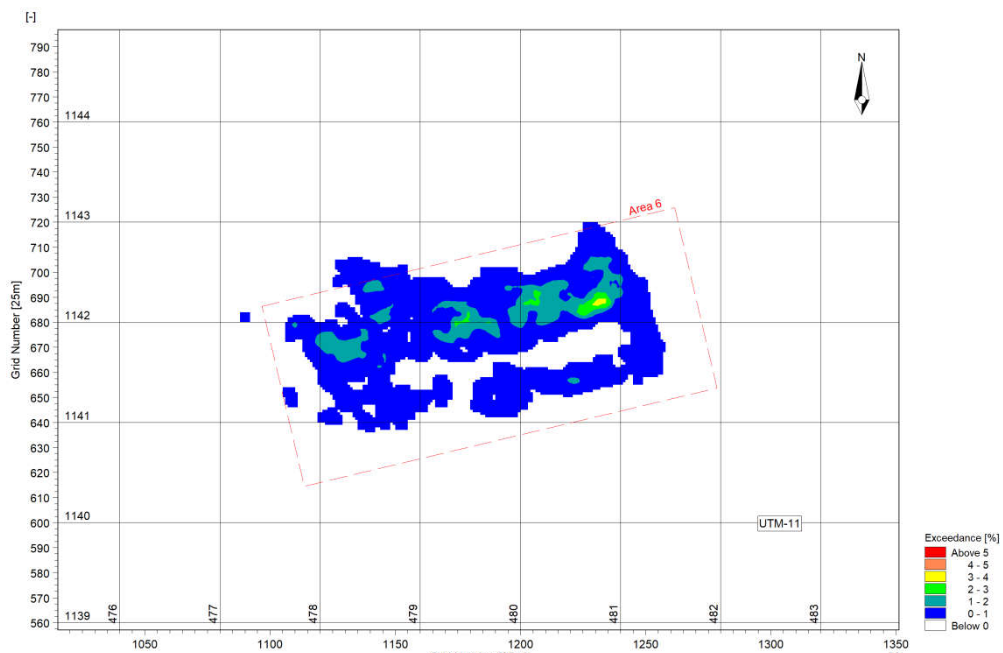

Figure 4.6 Net exceedance percentage of 5mg/l at 5m above the seabed from start of STR1b to 24hrs after completion of STR3b

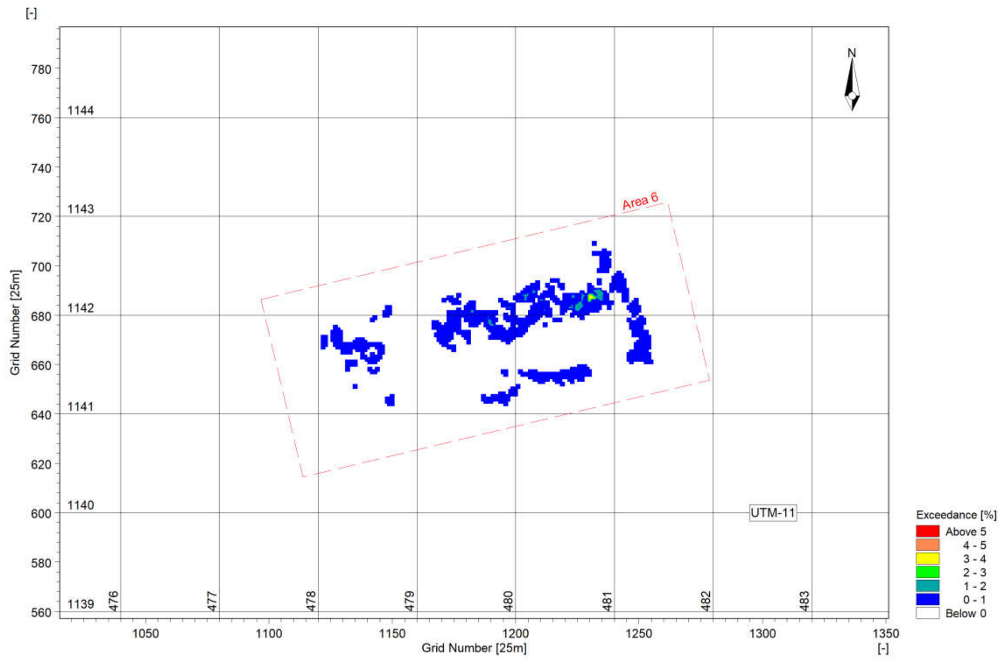

Figure 4.7 Net exceedance percentage of 10mg/l at 5m above the seabed from start of STR1b to 24hrs after completion of STR3b

4.2.2 TSS 20m Above Seabed

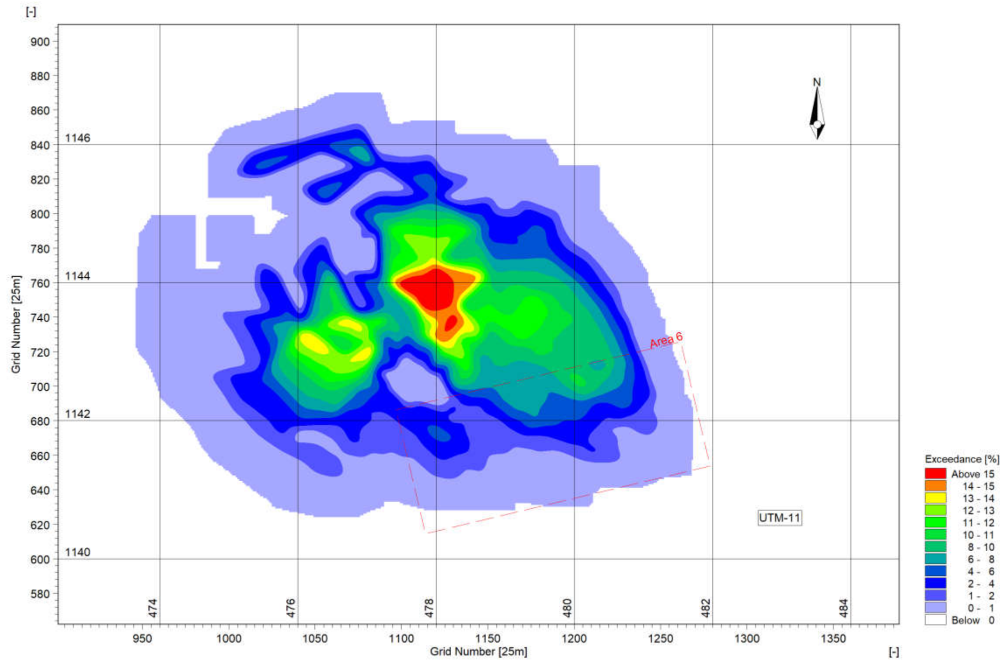

Figure 4.8 Net exceedance percentage of 0.1mg/l at 20m above the seabed from start of STR1b to 24hrs after completion of STR3b

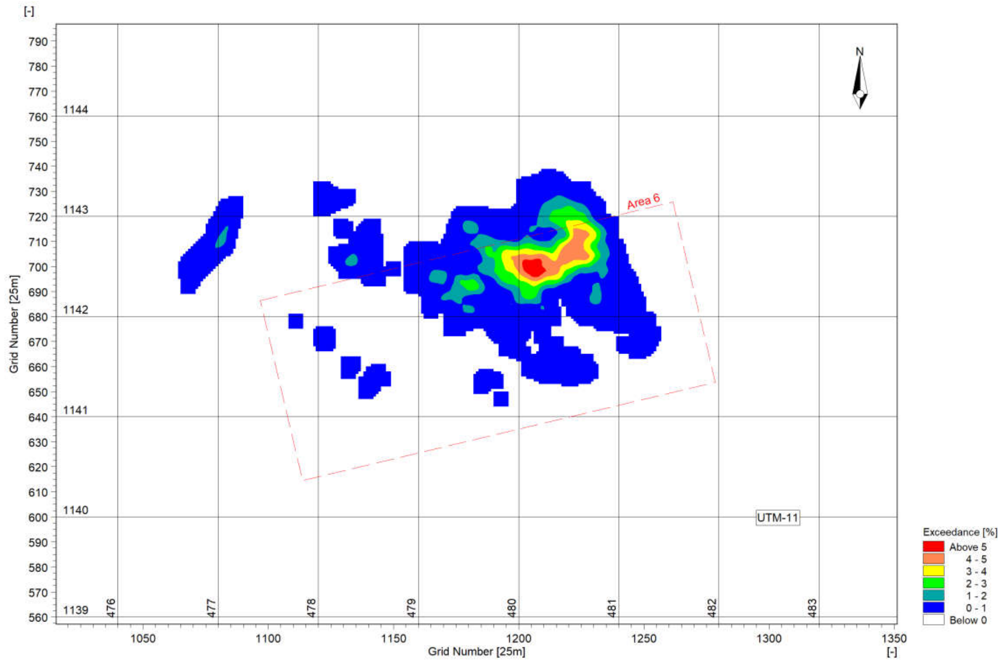

Figure 4.9 Net exceedance percentage of 1mg/l at 20m above the seabed from start of STR1b to 24hrs after completion of STR3b

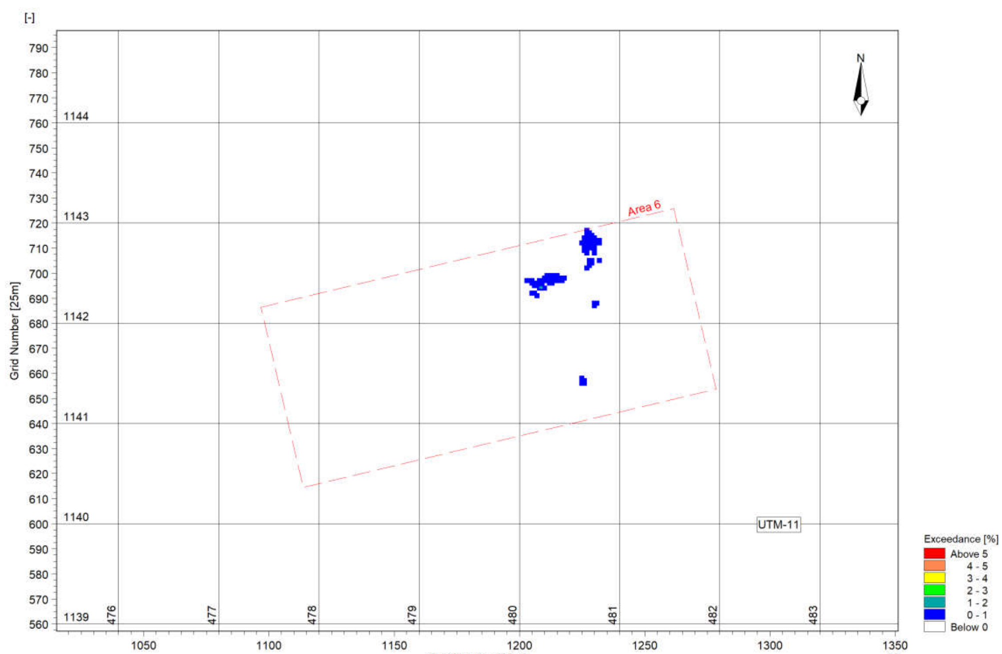

Figure 4.10 Net exceedance percentage of 5mg/l at 20m above the seabed from start of STR1b to 24hrs after completion of STR3b

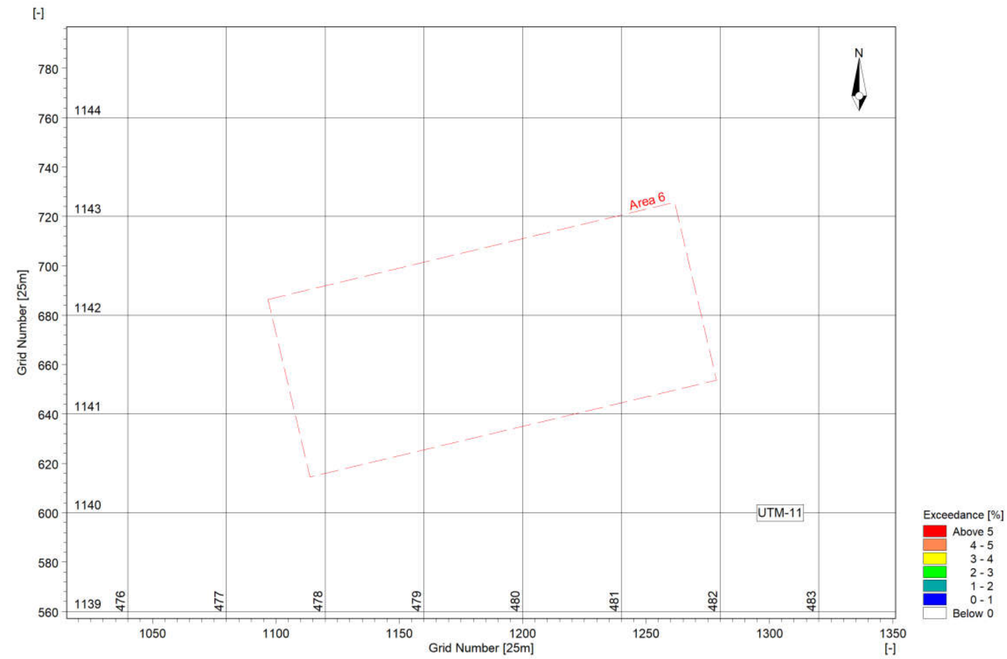

Figure 4.11 Net exceedance percentage of 10mg/l at 20m above the seabed from start of STR2a to 24hrs after completion of STR3b

4.2.3 TSS at Mid-Water Column Discharge

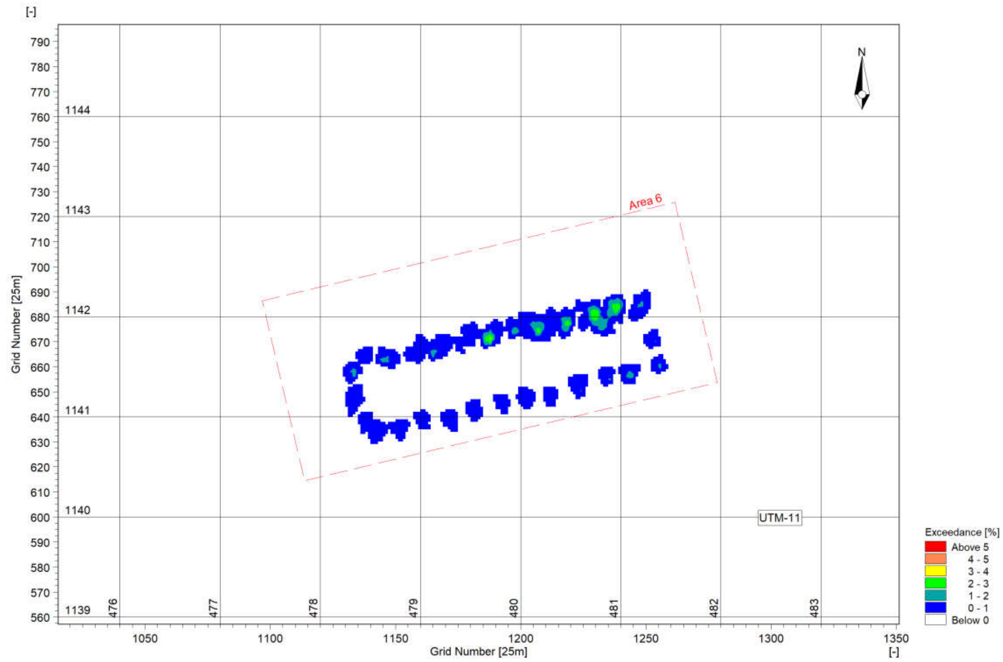

Figure 4.12 Net exceedance percentage of 0.1mg/l at 50m below the mid-water column discharge location (or 1050m below the surface) from start of STR2a to 24hrs after completion of STR3b

4.2.4 TSS Summary Statistics

Summary statistics for the cumulative pilot test operation are provided in the following figures. Results are presented for 5m above seabed, 20m above seabed and at 1050m for the mid-water column discharge for the following parameters:

Total duration (hours) where 1mg/l is exceeded. This is similar to the exceedance results presented in the previous sections, but expressed in hours rather than as a percentage of time.

***Time to first exceedance* of 1mg/l**. This provides an indicator of how long after the pilot test starts different areas will first experience concentrations above 1mg/l above background.

Number of times exceeded provides a description of the persistence of the exceedance events at a specific location. For example, a value of 12 would mean that the concentration went above and fell back below 1mg/l above background 12 times during the pilot test program.

4.2.4.1 Allseas Base Sequence

Figure 4.13 to Figure 4.21 present summary results for the Allseas base STR sequence presented in Table 4-2.

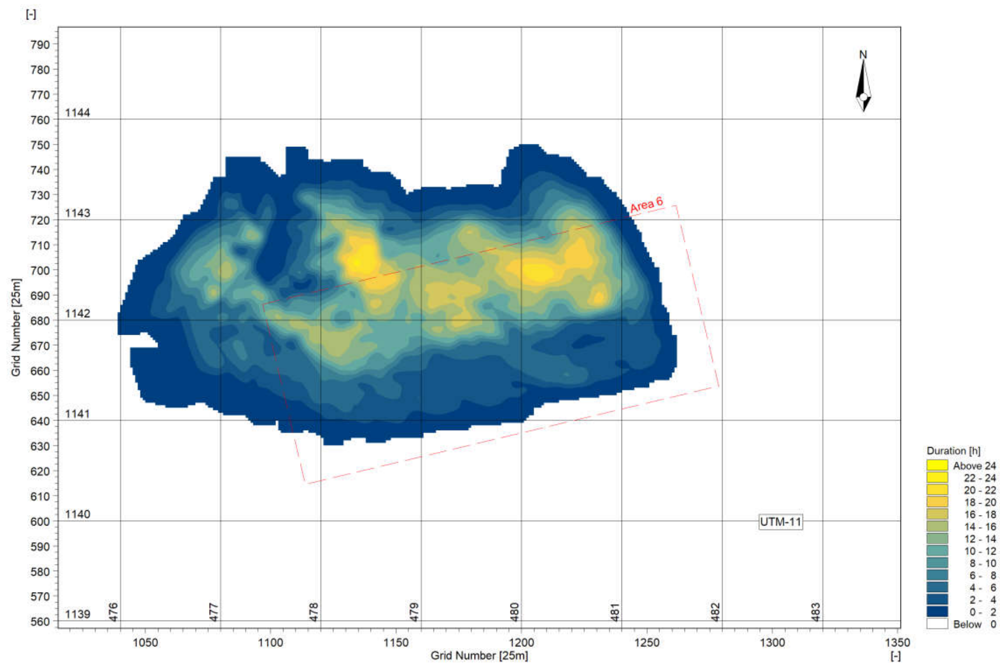

Figure 4.13 Total duration (hours) where 1mg/l is exceeded at 5m above the seabed

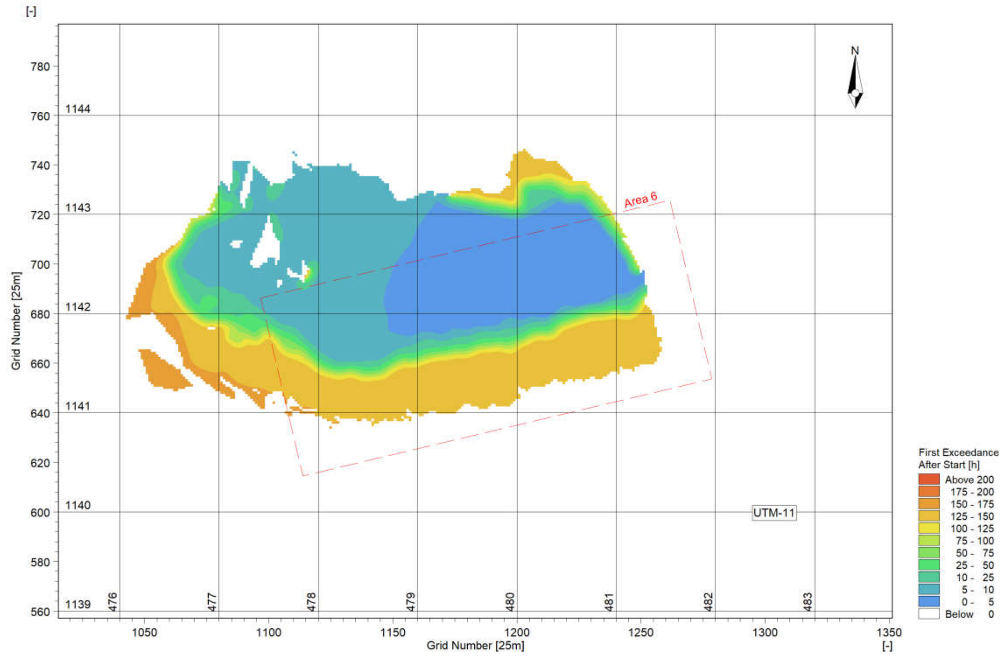

Figure 4.14 Time to first exceedance of 1mg/l after the start of each scenario at 5m above the seabed

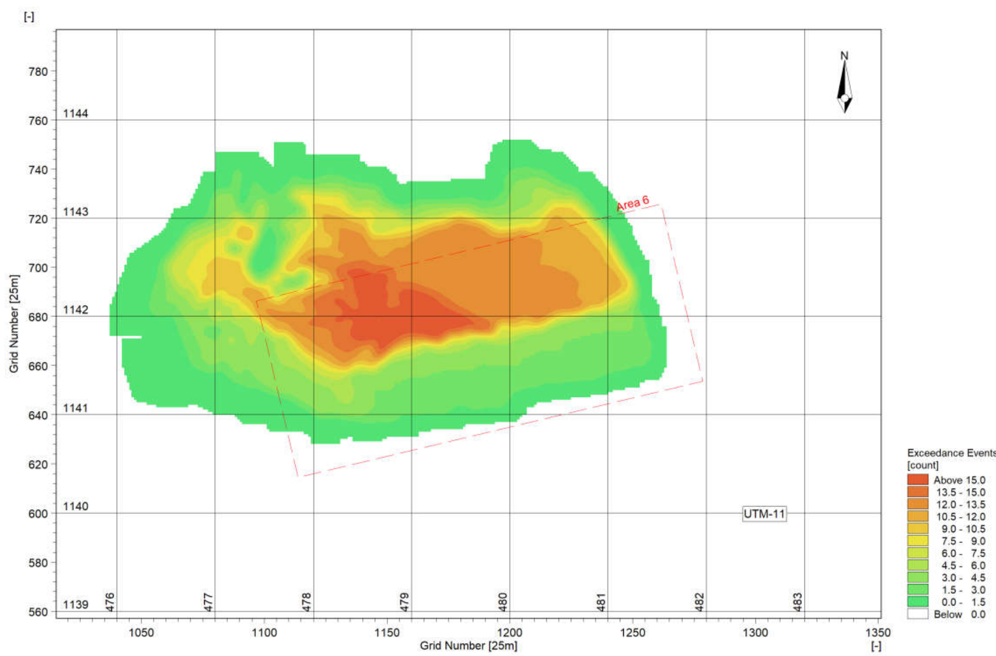

Figure 4.15 Total number of times the values in each cell exceed 1mg/l at 5m above the seabed

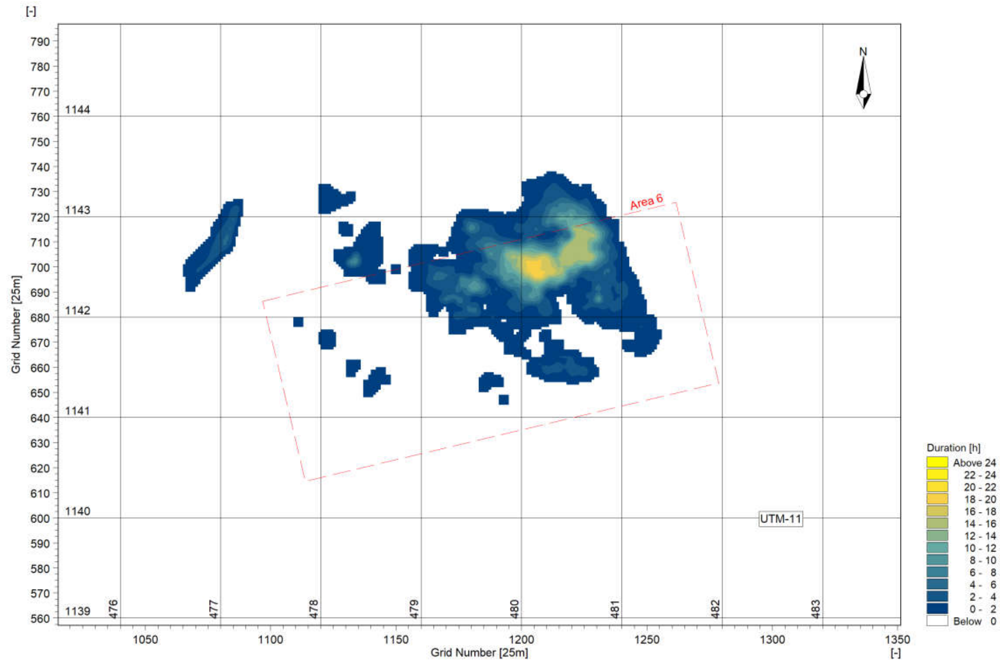

Figure 4.16 Total duration (hours) where 1mg/l is exceeded at 20m above the seabed

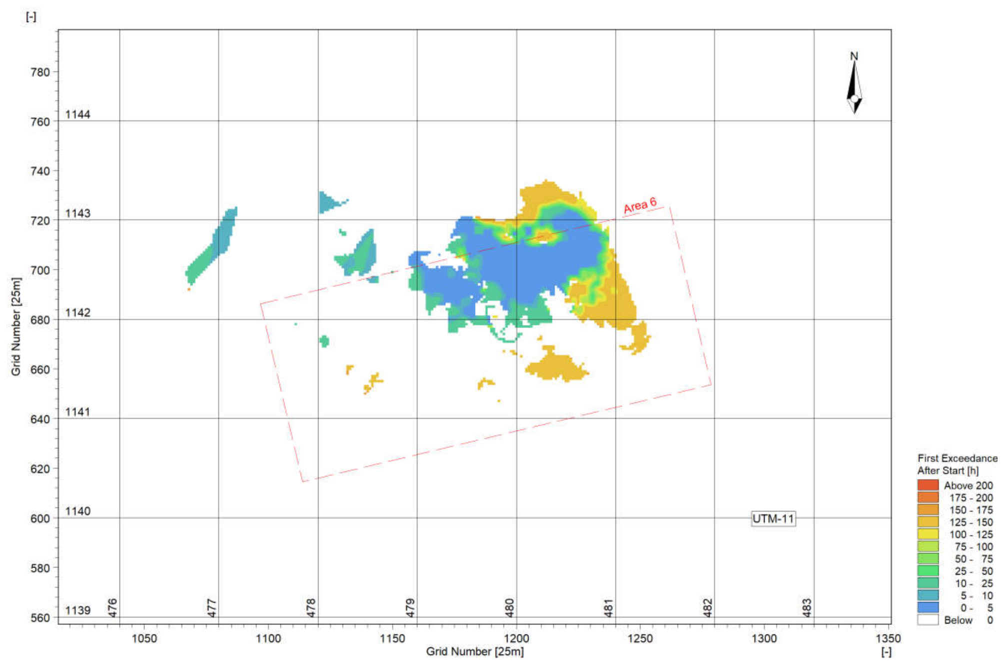

Figure 4.17 Time to first exceedance of 1mg/l after the start of each scenario at 20m above the seabed

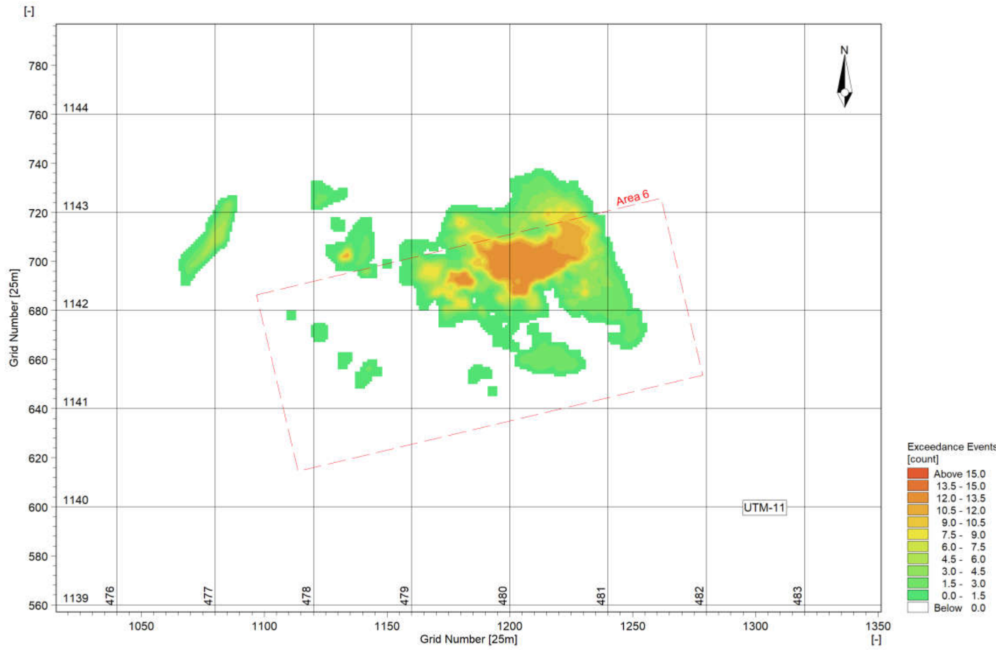

Figure 4.18 Total number of times the values in each cell exceed 1mg/l at 20m above the seabed

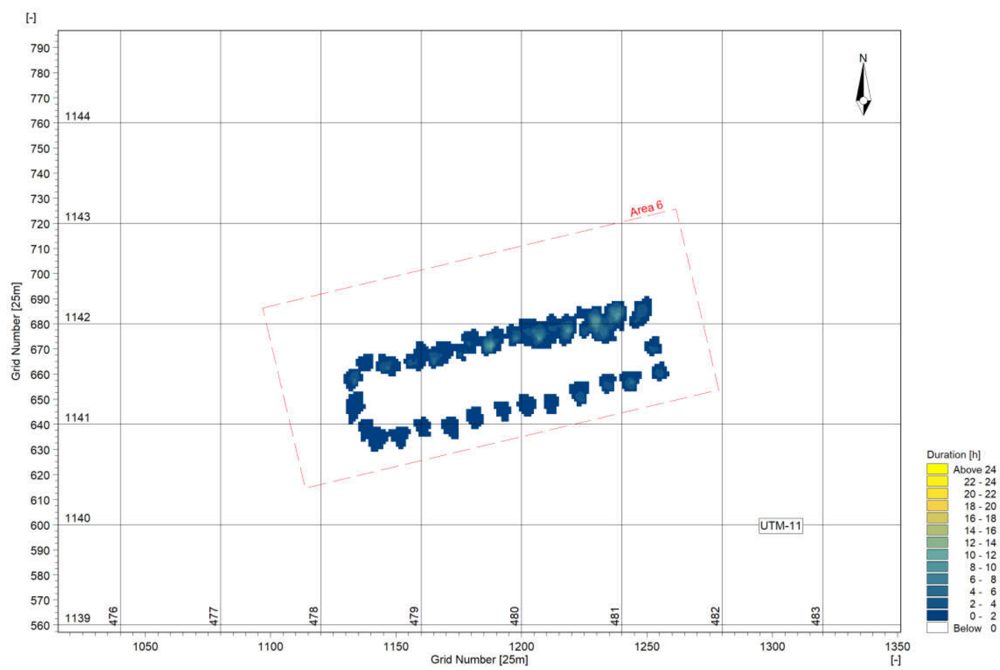

Figure 4.19 Total duration (hours) where 0.1mg/l is exceeded at 50m below the mid-water column discharge location (or 1050m below the surface)

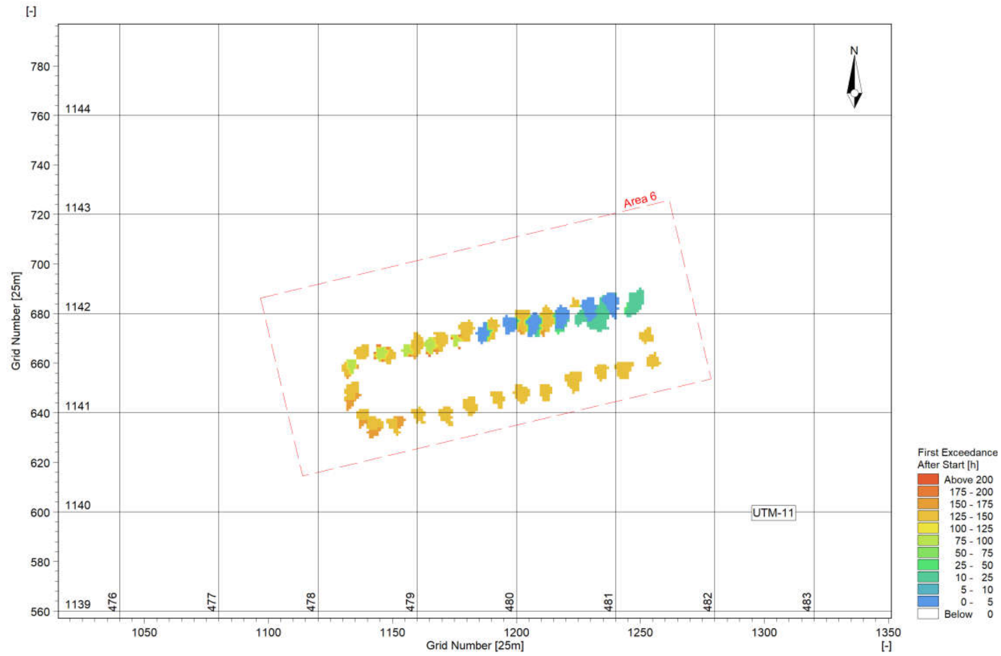

Figure 4.20 Time to first exceedance of 0.1mg/l after the start of each scenario at 50m below the mid-water column discharge location (or 1050m below the surface)

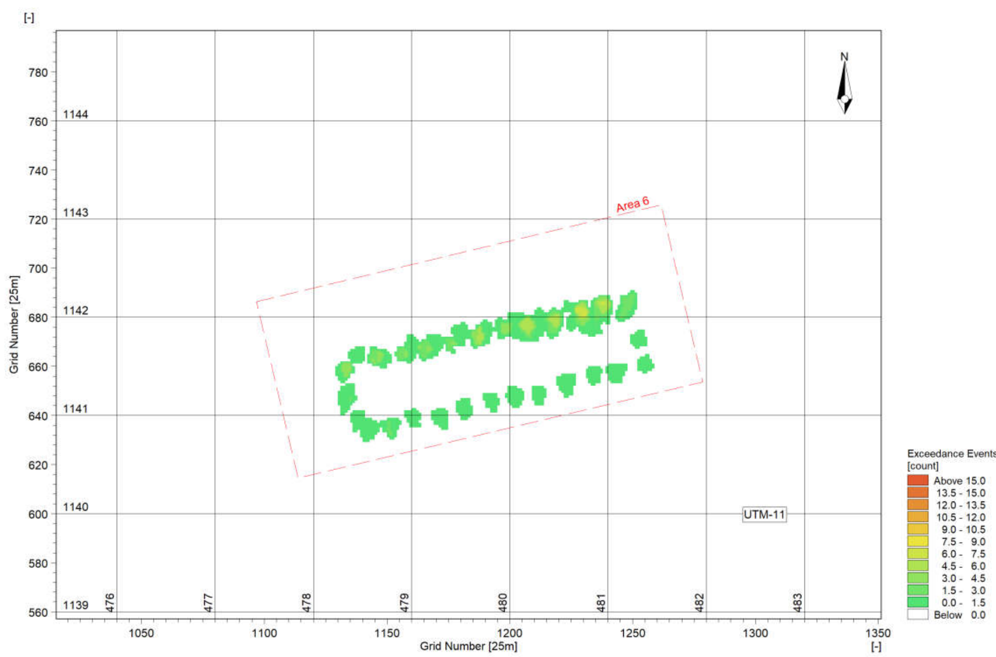

Figure 4.21 Total number of times the values in each cell exceed 0.1mg/l at 50m below the mid-water column discharge location (or 1050m below the surface)

4.2.4.2 Sensitivity to Sequence and Timing

As variation in the test sequence may occur due to operational reasons, the sensitivity of the suspended sediment results to the test sequence has been assessed (sedimentation being insensitive to the test sequence). The alternate test sequence is provided in Table 4-3, with results in in terms of total duration exceeding 1mg/l provided in Figure 4.22.

Table 4-3 STR sequence and start time offset for cumulative suspended sediment assessment with shifted sequence

STR Order	Total test time Per STR	STR start time shift from previous STR start
2a	95hrs	0
3a	41hrs	95hrs
1b	61hrs	41hrs
2b	29hrs	61hrs
3b	33hrs	29hrs

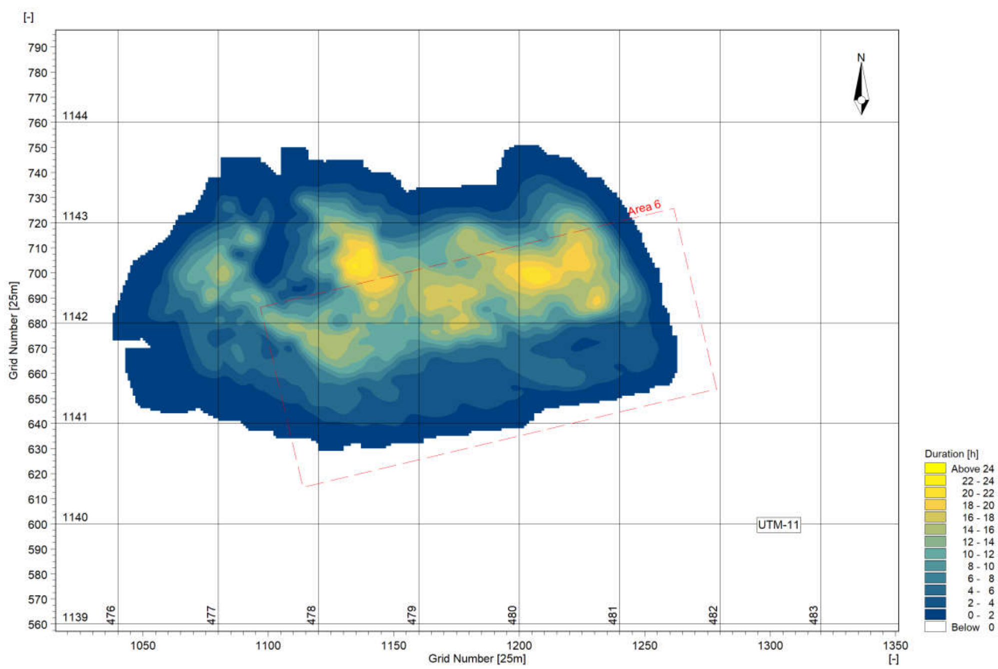

Figure 4.22 Total duration (hours) where 1mg/l is exceeded at 5m above the seabed. Alternate STR sequence per Table 4-3

Comparing the base sequence results (Figure 4.13) with those of the alternate sequence (Figure 4.22) only small differences can be observed. It is thus reasonable to conclude that, provided that the overall test sequence (of the main sediment plume generating tests) is carried out in a period not significantly different from that proposed by Allseas at the time of writing (259hrs) that the overall magnitude and spatial extent of the plume will be largely insensitive to the sequence of the specific STR tests.

Reducing the time between tests while maintaining production (Table 4-4) will ultimately tend to increase absolute cumulative magnitudes of exceedance. However, for the test sequence and time between tests put forward by Allseas (Table 4-2), there is significant leeway in the time between tests to avoid significant time overlap of the plumes. Consequently, even a 25% reduction in time between tests (Table 4-4) does not result in any appreciable change in cumulative exceedance of 1mg/l (Figure 4.23).

Table 4-4 STR sequence and start time offset for cumulative suspended sediment assessment with base sequence but with 25% reduction in test time

STR Order	Total test time Per STR	STR start time shift from previous STR start
1b	71hrs	0
2a	31hrs	71hrs
2b	46hrs	31hrs
3a	22hrs	46hrs
3b	25hrs	22hrs

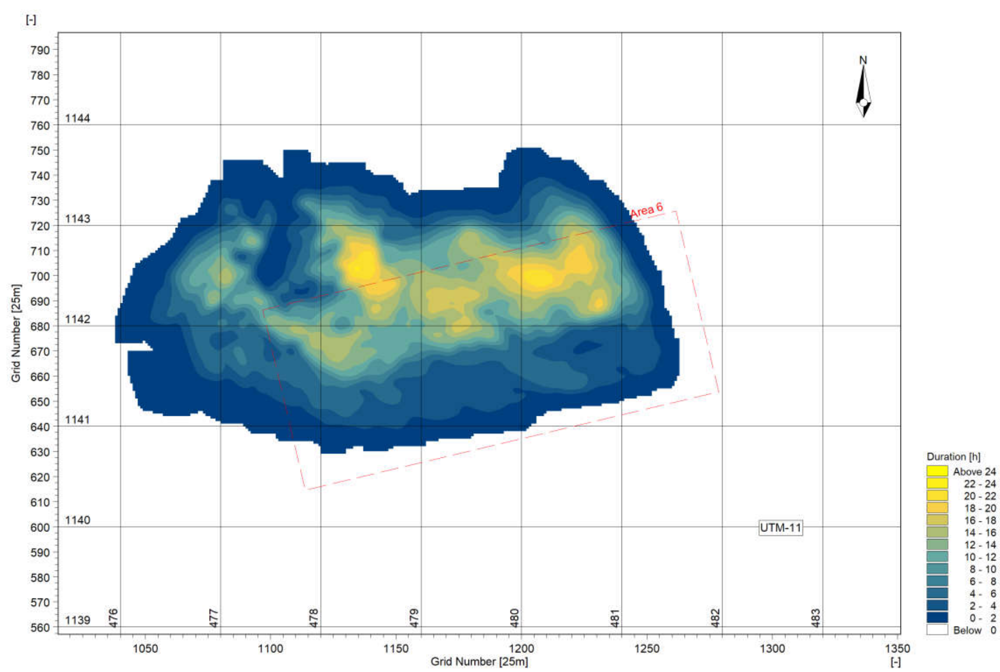

Figure 4.23 Total duration (hours) where 1mg/l is exceeded at 5m above the seabed. Alternate STR test timing per Table 4-4

Overall, provided production figures and production rates are closely adhered to, the sensitivity tests indicate that there is considerable flexibility in the sequence and schedule for the Pilot Collector tests without impacting the exceedance of a 1mg/l above background threshold.

4.3 Effect of Seasonality

As indicated in the preceding sections, the sediment plume modelling has been based on a pilot collector test program occurring during January 2022. This was the best information available at the time of simulation.

Ultimately it is recognized that the schedule for the pilot collector test may vary. Due to variability in the prevailing current conditions at the site (both seasonal and inter-annual variability due to the presence / absence of macro eddies, strength of oceanic processes etc.) some variability in the net migration of the sediment plume, depending on the ultimate schedule of the pilot test program, is to be expected. Figure 4.24 shows the average 2004 to 2018 monthly near-bed current roses based upon the HYCOM model data (HYCOM 2021) that are used as boundary conditions to the sediment plume model (Section 2.2). Based upon these current roses and consistent with the sediment plume results, a pilot collector test campaign undertaken during typical (i.e. average) January conditions is likely to see a north-westerly drift of the plume. Conversely, the same program occurring during June would likely see a net easterly plume drift, with a similar overall magnitude, but slightly higher spatial extent (in terms of area).

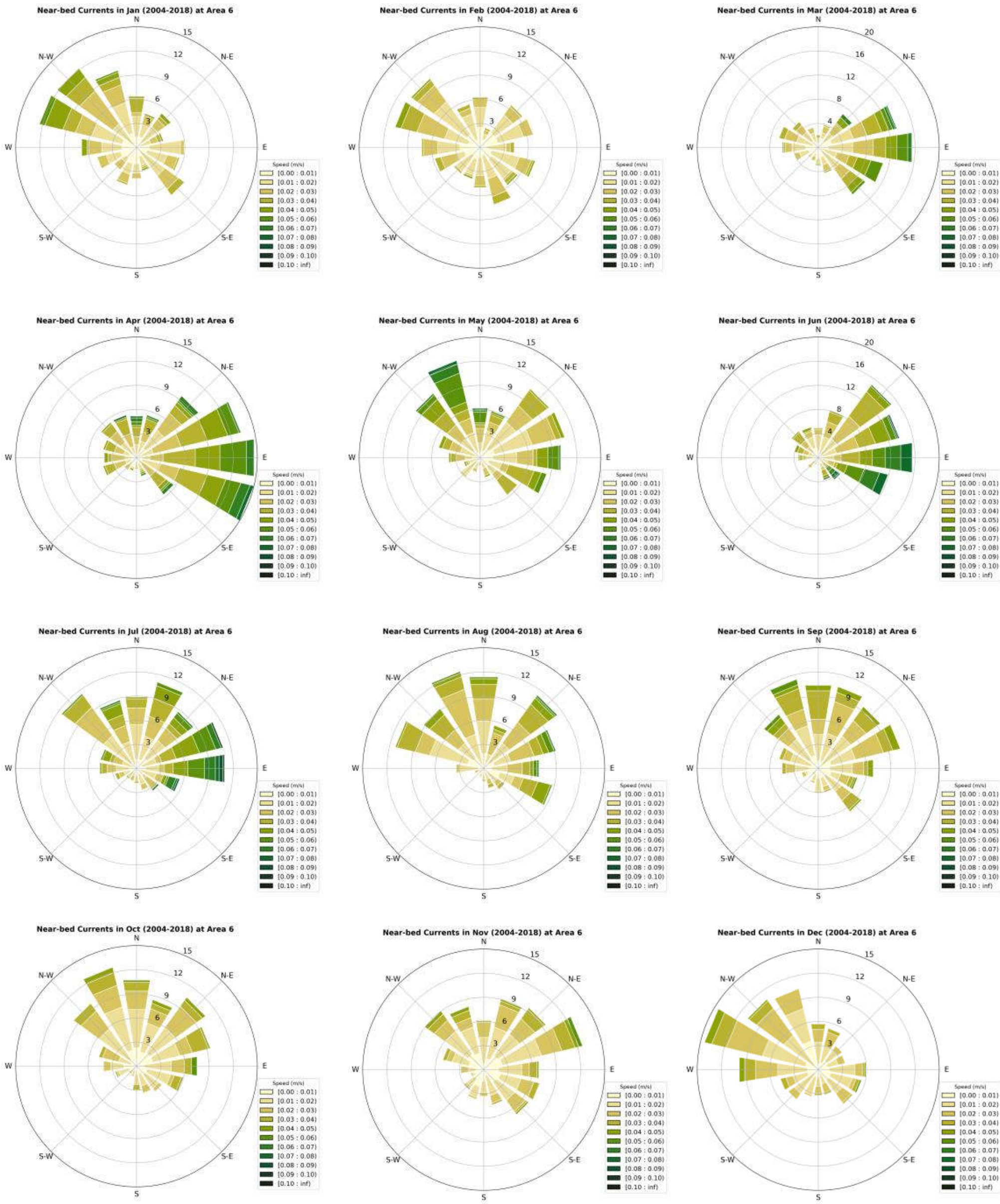

Figure 4.24 Seasonal variability in near bed current conditions (current flowing to) at the location of the long mooring in the NORI-D area based on HYCOM data 2004 to 2018 (HYCOM 2021)

4.4 Effect of Mid-water Column Discharge Depth

As indicated in the preceding sections, the sediment plume modelling has been based on a mid-water column discharge located at 1000m below the surface. This was the best information available at the time of simulation. Ultimately, design decisions may result in some minor (within a few 100m) adjustment to this discharge depth. Figure 4.25 presents the measured current conditions at approximately 1000m and 1200m below the surface from the NORI-D long mooring data available at the time of writing (CSA 2020). This indicates that, as expected, there is a slight decrease in current speed with depth, and a slight shift in the dominant current direction. It can thus be concluded that, while there will be some minor differences in the behaviour of the plume depending on discharge depth (slight change in spatial extent and slight change in dominant drift direction), but these differences will not be significant from an overall plume impact perspective for mid-water column discharges falling within this depth range of 1000m to 1200m.

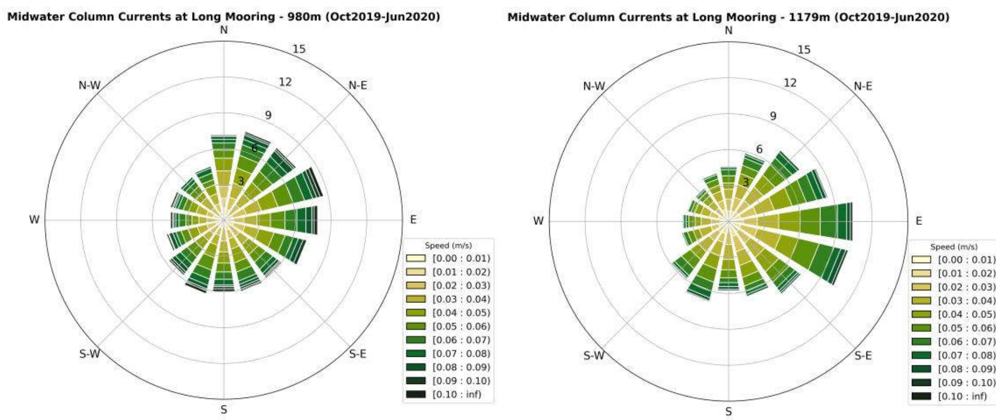

Figure 4.25 Measured current conditions at the NORI-D long mooring (current flowing to) at approximately 980m and 1179m (right) below the surface - 14 October 2019 to 26 June 2020

5 References

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