Appendix 12.2: Sediment Dispersion Study

URS-EIA-REP-204635

URS

South Stream Offshore Pipeline – Russian Sector

Sediment Dispersion Study

November 2013

4639088\RC_Sed\001

Prepared for:
South Stream Transport

UNITED KINGDOM

REVISION SCHEDULE

Rev	Date	Details	Prepared by	Reviewed by	Approved by
1	29/7/2013	Draft Report	Baoxing Wang Principal Coastal Modeller	Adrian Wright Principal Coastal Modeller	Paul Norton Head of Coastal
2	09/08/2013	Revised Draft - results from sensitivity testing with flocculation effects included	Baoxing Wang Principal Coastal Modeller	Adrian Wright Principal Coastal Modeller	Paul Norton Head of Coastal
3	21/08/2013	Revised Draft - results from sensitivity testing with flocculation effects included and updated plots with depth contours	Baoxing Wang Principal Coastal Modeller	Adrian Wright Principal Coastal Modeller	Paul Norton Head of Coastal
4	14/11/2013	Revised Draft - results from the comments	Baoxing Wang Principal Coastal Modeller	Adrian Wright Principal Coastal Modeller	Paul Norton Head of Coastal

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SUMMARY

As part of an Environmental and Social Impact Assessment (ESIA) for the South Stream Offshore Pipeline, URS was commissioned to assess the potential impacts of the various dredging and disposal operations in the Black Sea. This report provides the technical information relating to the methodology, data and modelling results for dredging and disposal operations adjacent to the Russian Coastline and offshore slope.

The dispersion of sediments from construction activities relating to the proposed pipeline placement was considered using the MIKE Flexible Mesh particle-tracking Model. This model simulates the release of sediment from either the surface or seabed as a result of dredging and disposal activities. The hydrodynamic data underpinning the modelling covers a period of 12 months and has been derived from the HYCOM (HYbrid Circulation Model) model (www.hycom.org). Two typical periods were identified to represent clockwise and counter-clockwise current conditions. The study follows a deterministic approach in which each simulation is conducted for a selected period.

The proposed dredging and disposal operations occur at different sections of the pipeline adjacent to the Russian coast and the offshore slope. Three operations have been identified for the study to represent a plume development during the construction of the pipeline installation, i.e. microtunnel exit pits/transition trenches, pre-lay dredging/disposal and post-lay trenching operation on the Russian slope. A range of thresholds of concentration (1mg/l, 2mg/l, 5mg/l, 10mg/l, 20mg/l and 50mg/l) have been used to define the scale of plume impact. In deep water sediment concentrations at the surface, bottom and through the water column (depth-averaged) have been investigated. The model shows that at the surface the plume will be a relatively small and barely visible. Close to the seabed, the plume is much larger in area and will include re-suspended sediment. The presence of the plume will persist throughout the construction dredging activities, gradually dissipating after they cease.

Dredging/dumping at the microtunnel exit pits/transition trenches results in the formation of a sediment plume after dredging works start. The sediment plume drifts in the direction of the ambient currents along the Russian coastline. The impact (for a 2mg/l threshold) is confined within a distance of 20km from the dredging and disposal location and the maximum area of the plume is approximately 40 km^2. On the Russian Slope, the operations consider multiple cycles of dredging and disposal activity for the pre-lay dredging, whilst only dredging activity is considered in the post-lay operation. The results show that the affected distance and area are dependent on current direction, position in water column and threshold of concentration, as summarised in Tables 3-2 to 3-9.

The sensitivity of flocculation was tested and the model results show that the plume is dispersed to a lesser degree when the flocculation process is activated in the model.

The formation of sediment flocs can be expected to result in a reduced extent of the sediment plume and a higher deposition.

1 INTRODUCTION

As part of an Environmental and Social Impact Assessment (ESIA) for the South Stream Offshore Pipeline, URS has been commissioned to assess the sediment concentration entrained in the water column resulting from the dredging and disposal activities associated with the Russian Sector of the South Stream Offshore Pipeline (the Project).

The dredging and disposal methods for the construction of the gas pipelines are expected to cause increases in turbidity and sediment dispersion. In order to assess this impact of these activities on the background turbidity, the MIKE Flexible Mesh (FM) Particle Tracking (PT) model has been applied in this study. The model simulates the release of sediment within the water column either from surface or the seabed as a result of dredging and disposal activities. This report provides the technical information relating to the methodology applied, the data and assumptions made along with a discussion of the results.

The proposed dredging and disposal operations occur at different sections of the pipeline from near the Russian coast to the offshore slope. Three operations have been identified for the study to represent plume development during installation of the proposed pipeline, these are:

- Microtunnel exit pits;
- Pre-lay dredging and disposal; and
- Post-lay trenching operation on the Russian Slope.

Figure 1-1 shows the three primary locations of dredging and disposal activity adjacent to the Russian coastline. Field survey information (sediment type, size and fraction) collected adjacent to the proposed sections of work were used to assist in the setup of the particle-tracking model.

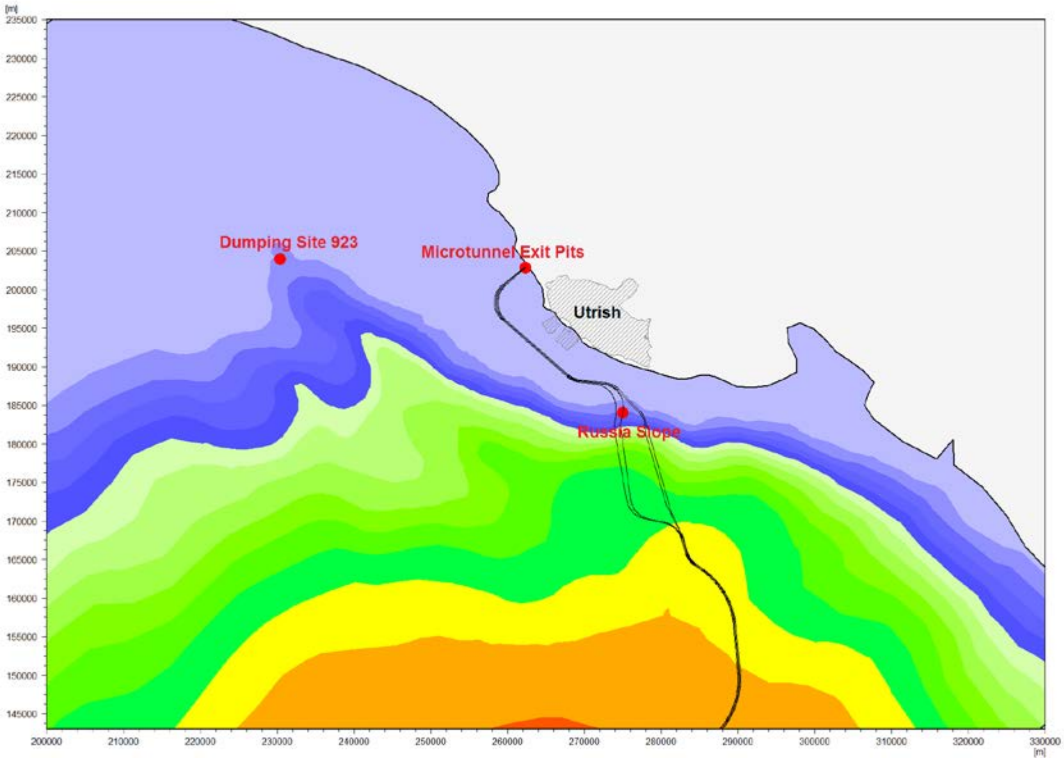


Figure 1-1 Dredging/Dumping Locations for the South Stream Offshore Pipeline

The key objective of this investigation is to provide information about the extent of any resulting sediment plume within the Russian coastal region. Any subsequent interpretation of the results should compare the predicted excess turbidity levels to background (or ambient) levels. A series of threshold excess sediment concentrations of 1mg/l, 2mg/l, 5mg/l, 10mg/l, 20mg/l and 50mg/l have been applied to assist with the interpretation of impacts due to the dredging and disposal activities. This information can be used when assessing the significance of impacts on environmental receptors within the region.

The study follows a deterministic approach in which each simulation is conducted for a selected period to include the influence of variations in current conditions. For each modelled scenario, the fate of the sediment plume has been simulated and the resulting maximum sediment concentration calculated for each defined model scenario.

This report describes the modelling approach, data inputs to the assessment (Section 2), modelling results (Section 3) and conclusions (Section 4).

2 MODELLING METHODOLOGY

2.1 Modelling Approach

The modelling work aims to estimates the extent and spread of sediment disturbed by the dredging and disposal activities from the proposed disposal sites. Sediment dispersion modelling using a particle-tracking approach has been used to investigate the spatial extent of plumes from the dredging and disposal operations. In order to describe the environmental conditions for the modelling, hydrodynamic conditions were taken from the existing HYCOM (HYbrid Coordinate Ocean Model) model and interpolated into the MIKE FM hydrodynamic model for the study area. The selection of the applied hydrodynamic conditions was based on data from 2008 as this was considered to provide representative conditions. Two periods were identified to give a representative assessment of the likely impact under clockwise and counter-clockwise current conditions.

To determine the increased levels of suspended sediment caused by the dredging activities, the PT model was setup with a sediment release represented in the model by a large number (several thousand) of 'particles', each representing a defined mass of sediment. The model traces the path of the particles over time and enables statistics to be developed about the fate of the sediment. Particles are tracked horizontally and vertically as dictated by the ambient currents and settling characteristics of the sediment. The simulation results were analysed to calculate the maximum suspended sediment concentration exceeding a defined threshold at every model cell.

For the assessment of potential impacts on water quality, in terms of elevated sediment concentrations, a series of minimum thresholds of 1mg/l, 2mg/l, 5mg/l, 20mg/l and 50mg/l above the reference concentration level have been considered.

2.2 The Particle Tracking Model

A three-dimensional (3D), PT model was applied to simulate the fate of sediment suspended by the proposed pipeline construction operations. The model predicts the transport induced by currents, dispersion, settling and re-suspension processes. The MIKE hydrodynamic (HD) model is used to provide a description of the current patterns which is underpinned by the HYCOM model which simulates the water flows in Black Sea and Russian Coastal area. The currents in this region are predominantly driven by the complex interaction of density gradients (due to freshwater inputs, atmospheric conditions and wind setup) local winds, astronomical and Coriolis forcing.

The PT model uses output from the HD model to predict particle movements in a Lagrangian manner. The flow regime is seeded with particles having defined properties, e.g. size, density, setting velocity and critical shear stress, etc. which are then tracked as they move with the flow. The PT model is capable of tracking the individual particles of different sizes from different sources and at different positions within the water column. This is a useful means of visualising flow patterns, particularly eddies and recirculation cells but can also be used to examine the movement of material from dredging and disposal activities.

The model outputs include spatial plot of sediment concentration resulting from the dredging and disposal operations.

2.3 Model Setup

The MIKE FM model covers an area of approximately 100 km by 80 km at a resolution which varies from 150m around the dredge site up to 5000m near the model boundaries away from the area of interest. The model domain is illustrated in Figure 2-1. The outputs from the HD model were applied in the PT model.

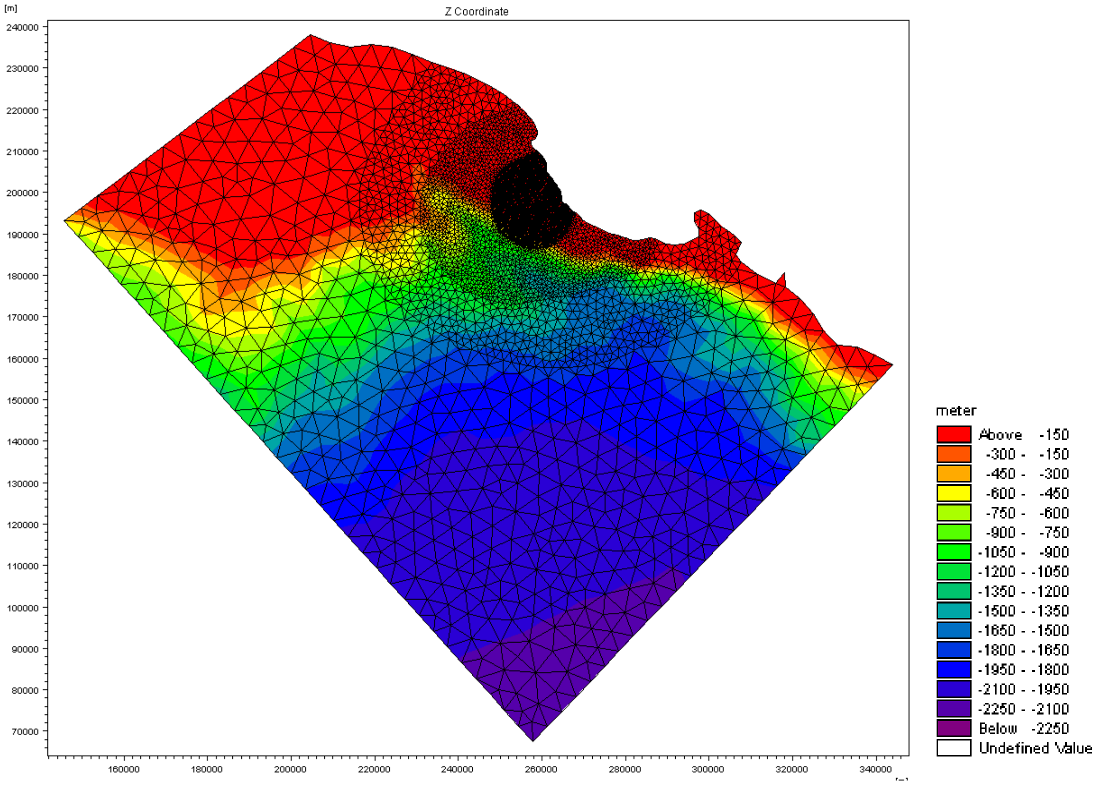


Figure 2-1: Russian Coastal Model Domain

Horizontal and vertical dispersion coefficients used in the simulations were set at 3 m^2/s and 0.3 m^2/s, respectively. These values are based on predicted conditions from the HD model and supported by typical values found in literature.

Wave-induced re-suspension of seabed sediments was not taken into account in this study as the proposed dredging/dumping operations are unlikely to be undertaken under a severe wave conditions.

2.4 Data and Inputs

2.4.1 *Hydrodynamics*

Hydrodynamic conditions within the Russian coastal area were simulated for a period of 12 months, from 1st January 2008 to 31st December 2008, based on current data extracted from the HYCOM model[1]. An example output from the HYCOM hydrodynamic model is shown in Figure 2-2.

The mid-depth currents and water levels were stored in a hydrodynamic database to be read by the PT model. This 1-year database captures a wide variety of possible hydrodynamic conditions.

The HYCOM model is based on a 1/12^{o} grid resolution. Through the vertical the HYCOM model has a total of 33 layers describing the vertical structure of the water column in terms of current speeds, salinity and density. The HYCOM model has a high number of layers situated at the surface in order to capture the often complex density variations and as such current regimes within the upper water column.

Information has been directly taken from the HYCOM model and independently checked to ensure that the flow direction and magnitudes are consistent with reported literature. The HYCOM model data has then been interpolated into the MIKE FM software and used as the main forcing condition within the PT module.

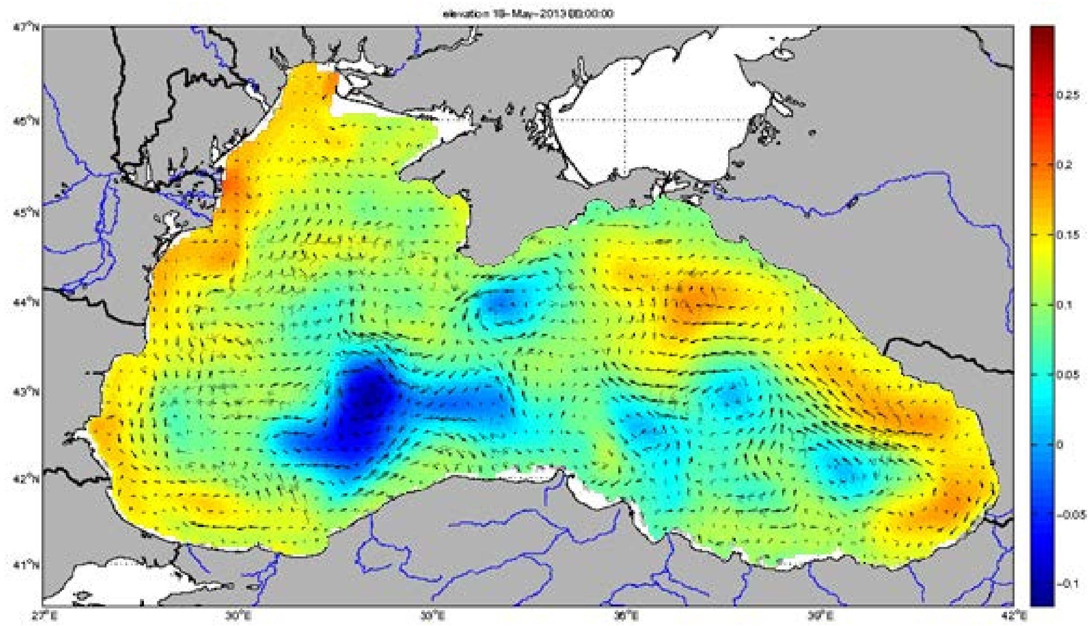


Figure 2-2. Example Hydrodynamic Output (m/s) from the HYCOM Model Used to Underpin the Sediment Dispersion Modelling.

[1] http://hycom.org/

2.4.2 *Simulation Period*

A current rose is plotted in Figure 2-3 for the 2008 data, which shows two dominant current directions associated with the strongest current speed. Simulations have therefore been run during two representative periods in January and April 2008. It is worth mentioning here that this study does not intend to investigate seasonal variations but instead represents typical worst-case conditions that can be expected to occur. During these months the current direction remains uniform although there are fluctuations in the peak current magnitude. The model run duration is 15 days for each scenario which covers a complete dredging and disposal operation and allows sufficient time for the plume to fully develop. Typical variations in current speed and direction are illustrated in Figures 2-4 to 2-7.

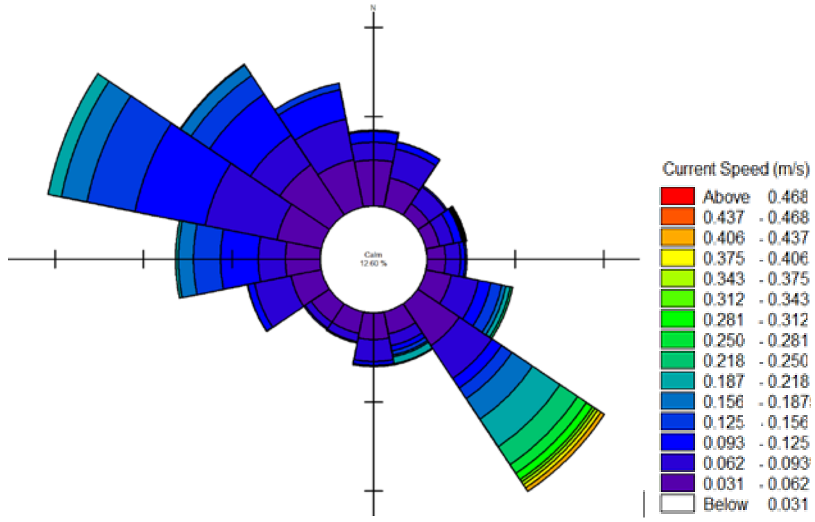


Figure 2-3 Current Rose Plot

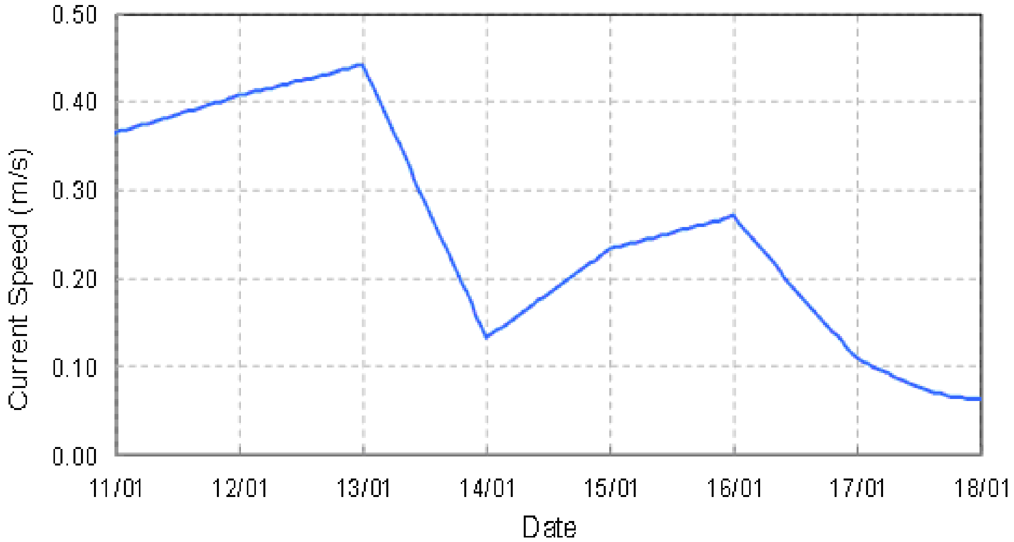


Figure 2-4 Current Speed in January 2008

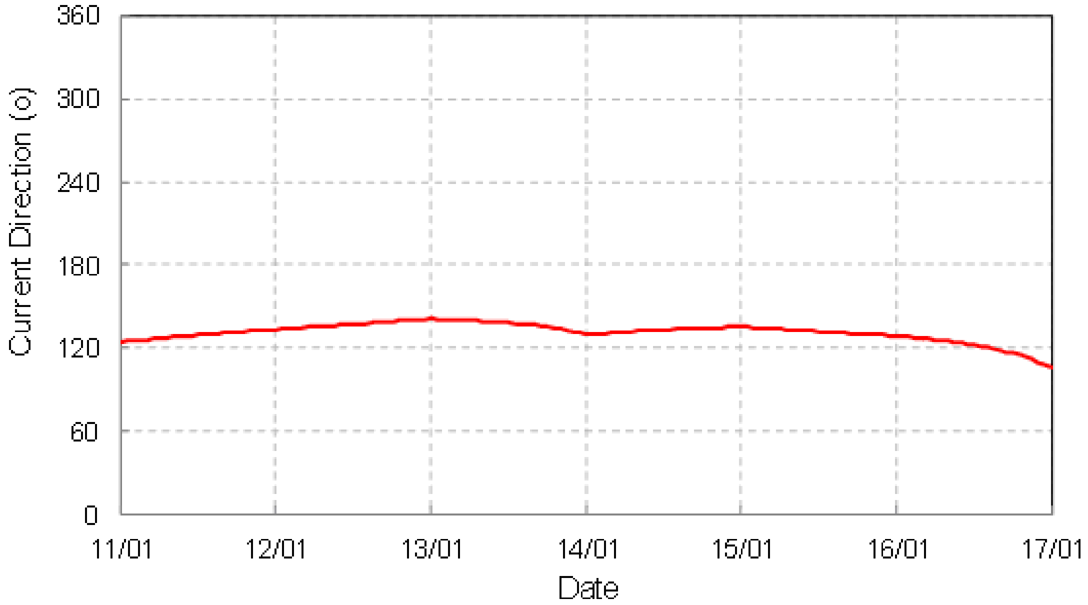


Figure 2-5 Current Direction January 2008

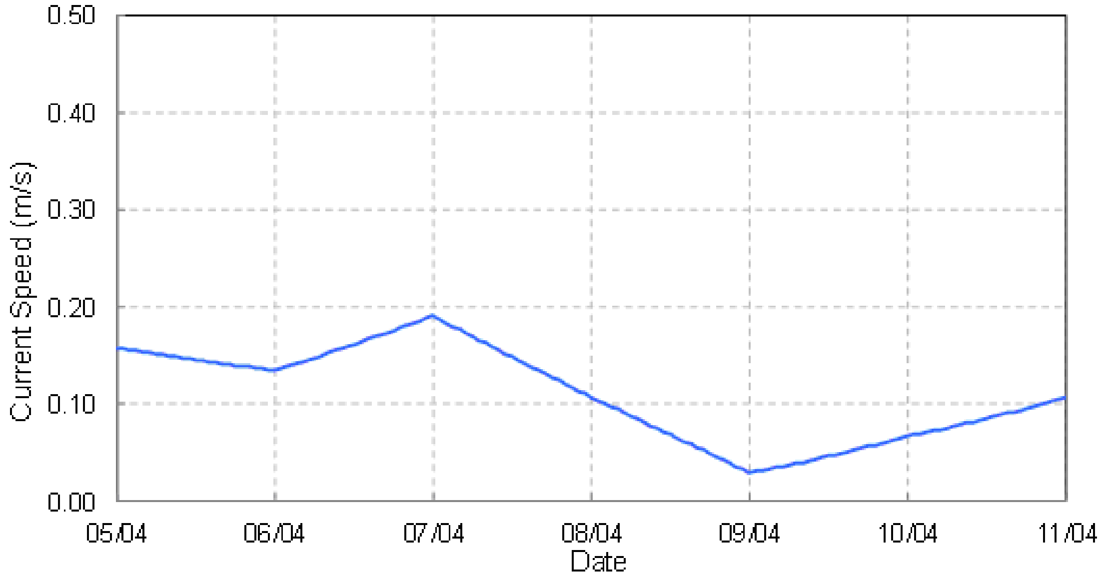


Figure 2-6 Current Speed in April 2008

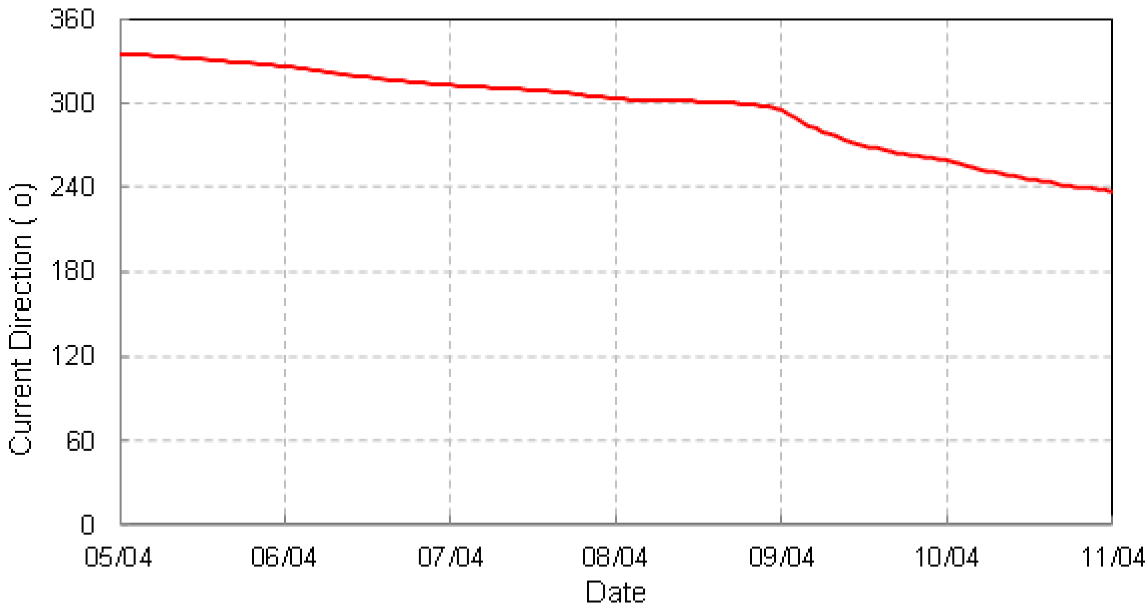


Figure 2-7 Current direction in April 2008

2.4.3 *Particle Properties*

Sediment particle size information was derived from the survey data provided in the Peter Gaz Report (2013). The sediment data obtained from the relevant locations were analyzed and grouped, as required to determine the model input. The representative particle sizes and associated fractions are given in Table 2-1 and Table 2-2.

Considering the range of sediment particle sizes, the process of aggregation (flocculation) and break-up may occur. The degree of flocculation is highly dependent upon both the sediment concentration and degree of turbulence which vary both spatially and temporally. Flocculation typically increases the fall velocity and critical shear stress and can therefore have a significant impact on plume characteristics. During the dredging process the degree of flocculation is likely to be significantly reduced due to the high levels of turbulence which will prevent large flocs from forming. Sensitivity tests have been carried out to better understand the implications of the flocculation process and to ensure that potential impacts under worst-case conditions are evaluated.

The fall velocity for the various sediment sizes was estimated using Figure 2-8 taken from the project survey report. The critical shear stress, which defines a threshold at which sediment is likely to move based on the sediment size, was calculated using the formulation by Soulsby (1997) which assumes no flocculation. Table 2-1 and Table 2-2 summarise the sediment parameters applied in the model.

Table 2-1 Sediment Parameters at the exit pits

Particle size (mm)	Fraction	Fall velocity (m/s)	Critical Shear Stress (N/m^2)
0.003	30%	8.0E-6	0.013
0.010	37%	9.0E-5	0.039
0.100	33%	9.0E-3	0.143

Table 2-2 Sediment Parameters on Russian slope

Particle size (mm)	Fraction	Fall velocity (m/s)	Critical Shear Stress (N/m^2)
0.003	46%	8.0E-6	0.013
0.010	38%	9.0E-5	0.039
0.100	16%	9.0E-3	0.143

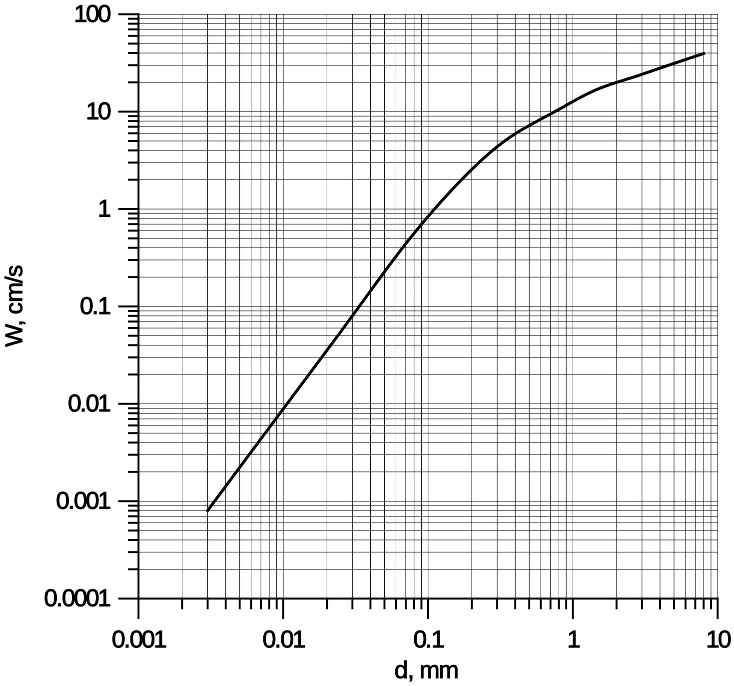


Figure 2-8 Plot Showing Sediment Fall Velocity vs Sediment Size

3 MODELLING RESULTS

3.1 Modelling Scenarios

The relevant seabed intervention activities that have been modelled consist of: dredging microtunnel exit pits and transition trenches; pre-lay dredging on the Russian continental slope; and post-lay trenching operation on the Russian continental shelf. Each operation is simulated for two selected periods under clockwise and counter-clockwise current conditions. The key locations and typical current fields are illustrated in Figures 3-1 and 3-2. For the possible operation period, each phase of pipeline construction has been considered as a separate operation. Only the maximum dredging and disposal volumes associated with the dredging/trenching for one pipeline have been considered as they are likely to cause the most significant increase in turbidity

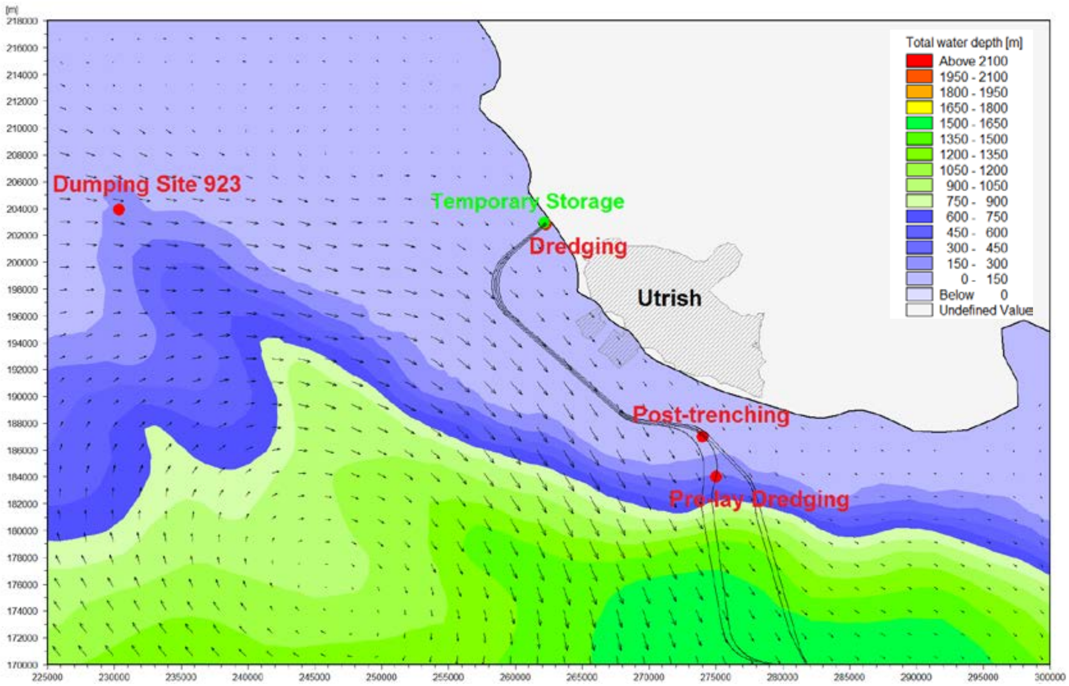


Figure 3-1 Dredging and Disposal Locations (Clockwise Currents)

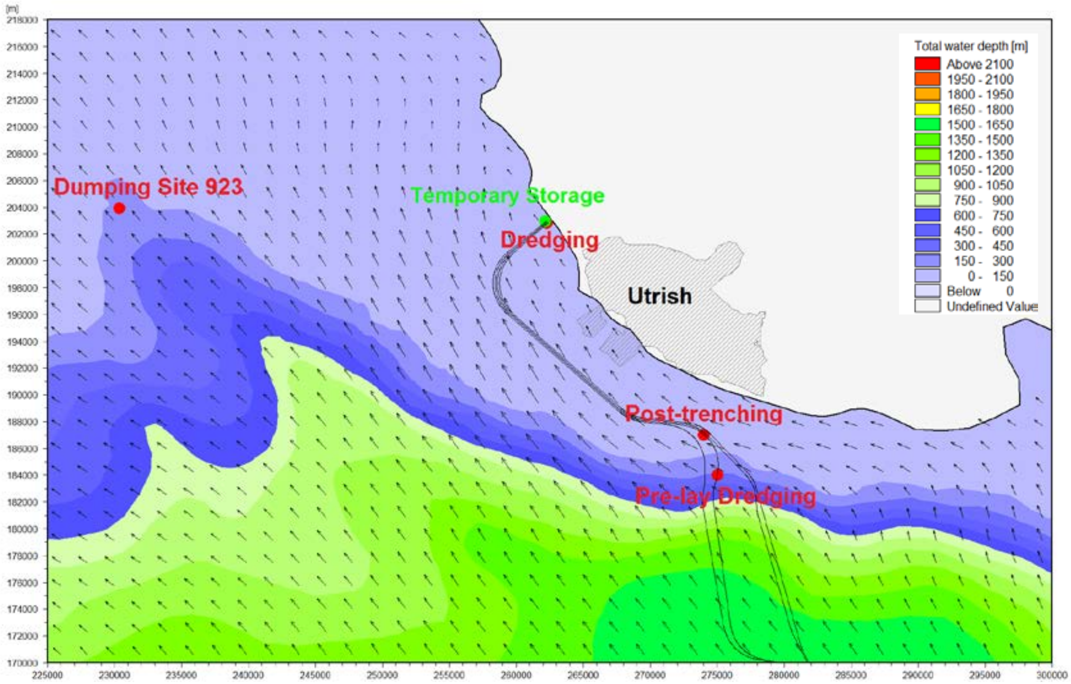


Figure 3-2 Dredging and Disposal Locations (Counter-Clockwise Currents)

For the dredging activities at the microtunnel exit pits/transition trenches, the material is dredged and stored in a temporary storage site, then dredged back up and backfilled into the exit pits/transition trenches. It has been assumed that the material is transported using a floating hose into the vicinity of the temporary storage site. For the post-lay operations as occurring on the shelf, the material is assumed to be pushed to the side of pipeline. Where pre-lay dredging is undertaken on the continental slope the dredged material shall be loaded to barges and transported to the permanent disposal site, Area 923.

In total, six scenarios have been derived which represent the different locations for dredging and disposal activities under the two defined hydrodynamic conditions, these scenarios are defined in Table 3-1.

Scenario 1: Dredging of the microtunnel exit pits/transition trenches; temporary storage using a floating hose; sediment release under clockwise currents.

Scenario 2: Dredging of the microtunnel exit pits/transition trenches; temporary storage using a floating hose; sediment release under counter-clockwise currents.

Scenario 3: Pre-lay dredging on the Russian slope; designated disposal area; 16 trips, 7.0hrs sailing duration; sediment release under clockwise currents.

Scenario 4: Pre-lay dredging on the Russian slope; designated disposal area; 16 trips, 7.0hrs sailing duration; sediment release under counter-clockwise currents.

Scenario 5: Post-lay trenching operation on the shelf; sediment release under clockwise currents.

Scenario 6: Post-lay trenching operation on the shelf; sediment release under counter-clockwise currents.

Table 3-1 Model Scenarios

Scenarios	Current condition	Particle release in water column	
		Dredging	Disposal
1	Clockwise	Surface	Surface
2	Counter- clockwise	Surface	Surface
3	Clockwise	5m from seabed	10m from seabed
4	Counter-clockwise	5m from seabed	10m from seabed
5	Clockwise	5m from seabed	N/A
6	Counter-clockwise	5m from seabed	N/A

Table 3-2 Volume and Mass Flux Calculations (Based on data received from Peter Gaz)

Scenarios	Operation	Volume m^3	Volume passing to a suspension m^3	Mass passing to a suspension, t	Mass flux (kg/s)
1 & 2	Dredging	25000.0	125	165.63	1.5
	Disposal	25000.0	7675	10170.0	91.0
3 & 4	Dredging	15,000	5100 (34%)	6717.75	62.2
	Disposal	15,000	5100 (34%)	6717.75	233.3
5 & 6	Dredging	11,000	1540 (14%)	2055.075	11.3

The volume and mass flux calculations used for the model setup are provided in Table 3-2. The values have been interpreted and used by URS based on the values provided by Peter Gaz Report (2013).

3.2 Results

The time-step of the particle tracking simulation was set at 300s (5mins). At every time-step material is released into the water column based on the specific scenario tested (Table 3-1). At the microtunnel exit pits, the depth-averaged suspended concentrations are investigated; whilst in the deep water on the Russian slope, sediment concentrations 10m below the water surface, 10m above the seabed and values averaged over the entire water column are presented for each element. At the end of each simulation (15 days), the maximum sediment concentration that occurs within each model element is calculated. The final maximum concentration results are therefore not a representation of any point in time but are instead a time independent view of the sediment plume extent. In reality, the actual sediment concentration at any point in time is likely to be much lower.

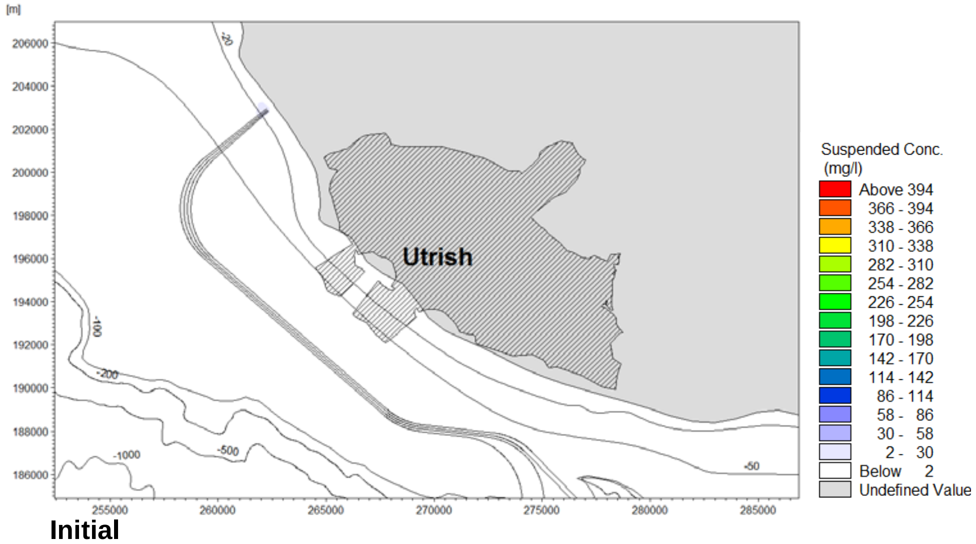
3.2.1 Dredging/Dumping at Microtunnel Exit Pits

The representative snapshots of the plume development (>2mg/l) at the microtunnel exit pits are shown in Figures 3-3 and 3-4 for two current directions. It can be seen that the plume is created immediately after dredging works starts, and disperses in the direction of the dominant current direction along the Russian coastline.

Additional post-processing of model results has been conducted to obtain maximum values. Figures 3-5 to 3-6 illustrate the map plots of maximum concentration over 15 days for a threshold is 2mg/l. The impact in terms of the extent and area affected has been derived from the model results for six thresholds: 1mg/l, 2mg/l, 5mg/l, 10mg/l, 20mg/l and 50mg/l. The results are summarised in Table 3-3.

The recorded maximum concentrations are 1300mg/l under clockwise current conditions and 5600mg/l under counter-clockwise current condition. The impact defined by a concentration of 2mg/l is confined within a distance of 20km from the dredging and disposal location where the maximum area of the plume is approximately 40 km^2. The model results show that the sediment plume (>2 mg/l) disturbed by the works would disappear within 5 days.

Figures 3-7 and 3-8 present the sediment thickness (mm). The recorded maximum thickness of deposition on the sea bed is 20mm for Scenario 1 and 74mm for Scenario 2 near the dumping site, based on a typical in-situ density.



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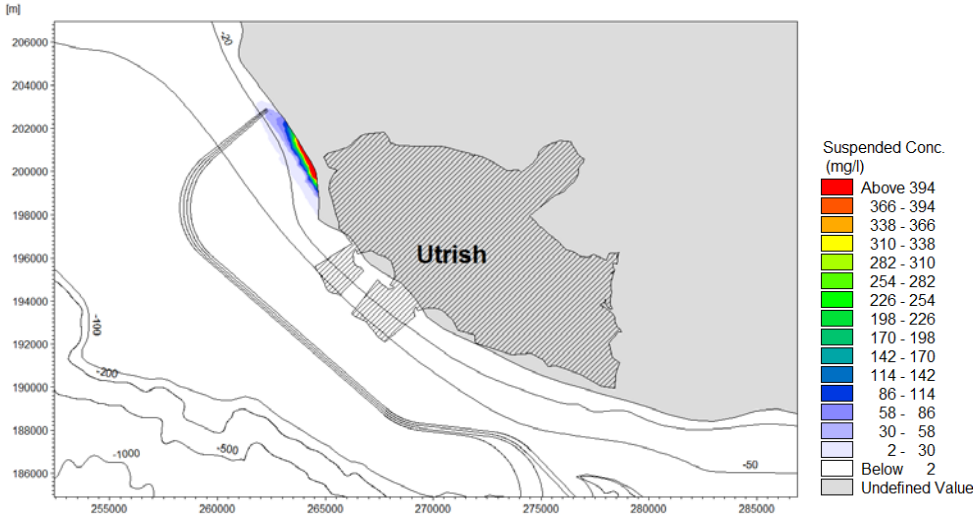

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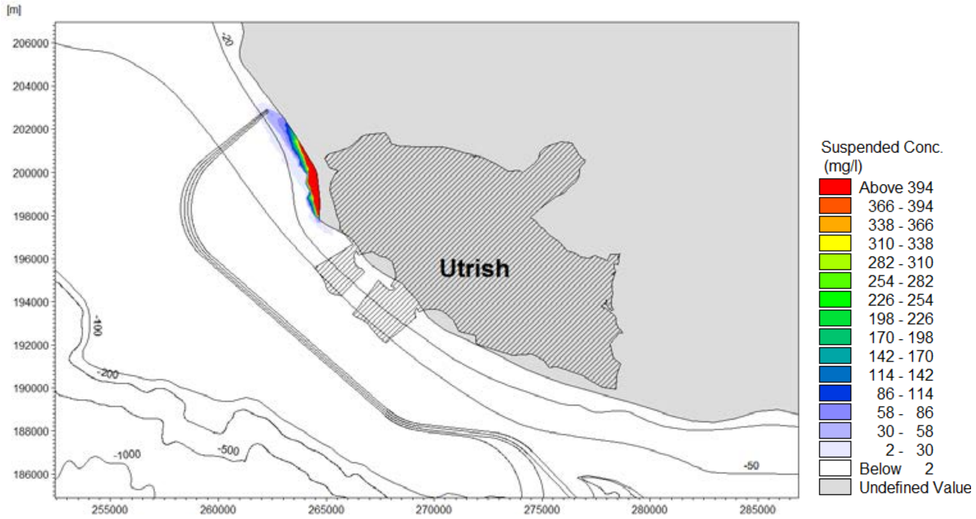
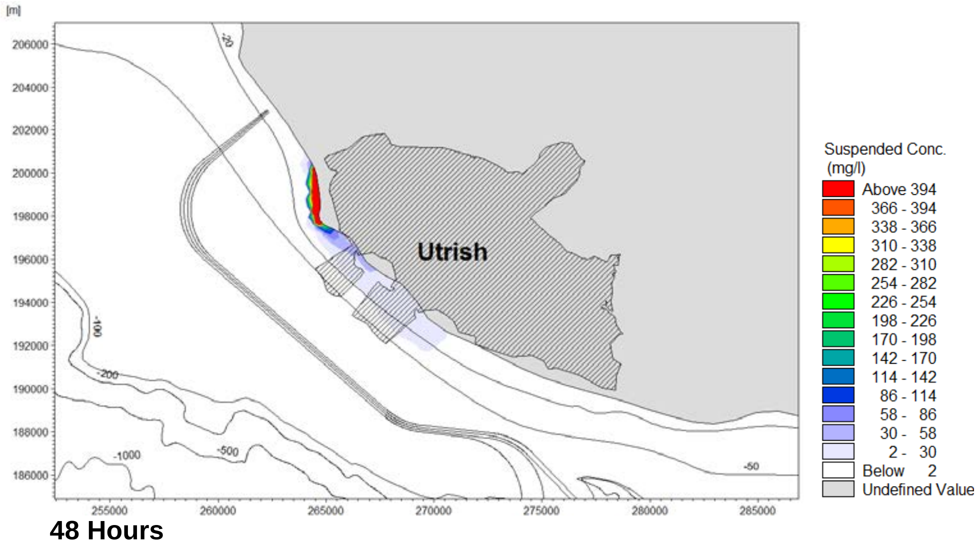


24 Hours

Figure 3-3a Plume Development under Clockwise Currents (Scenario 1)



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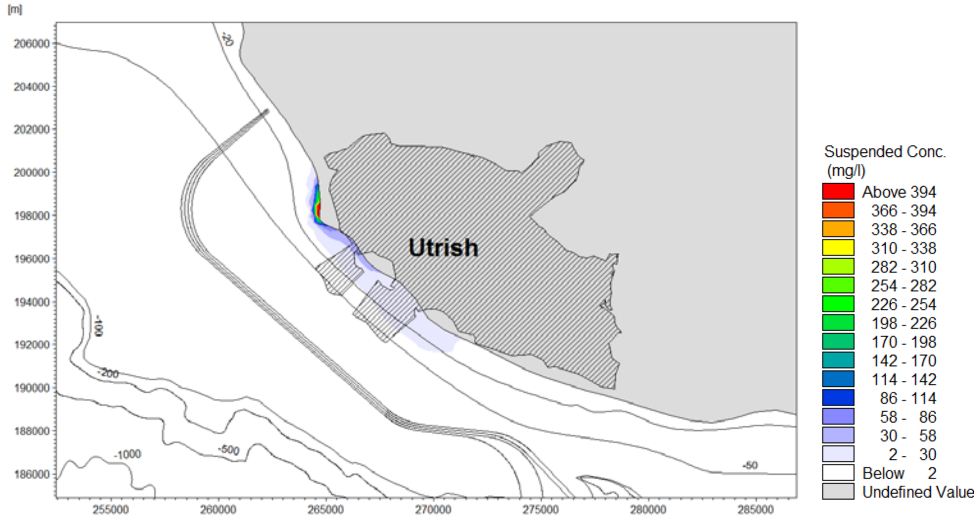

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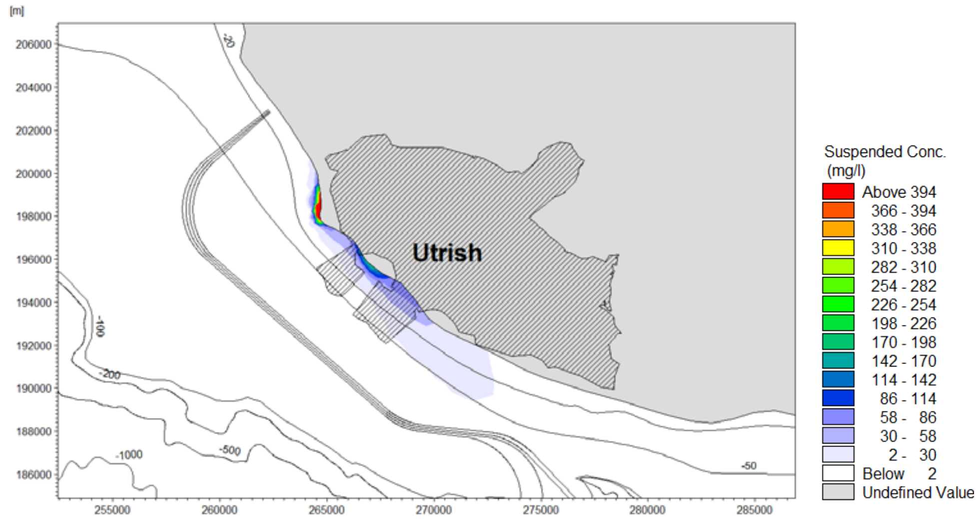
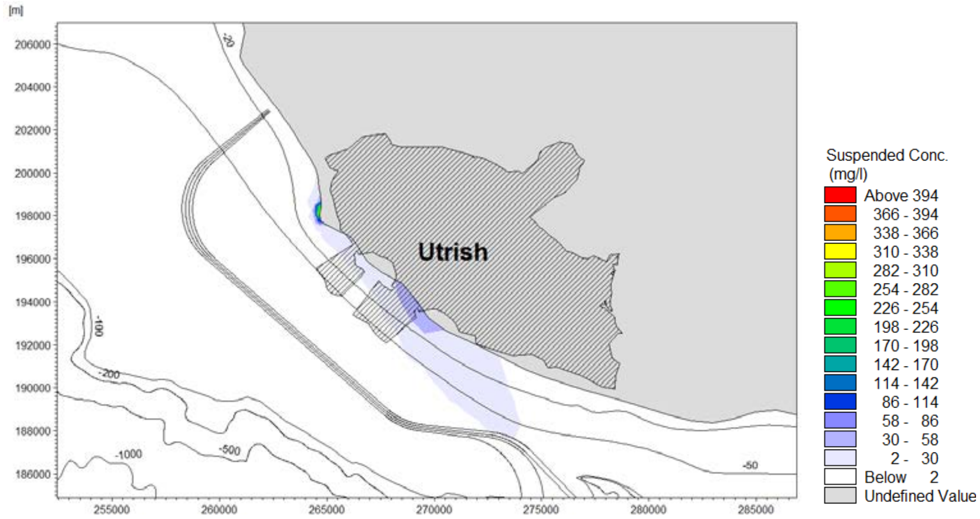
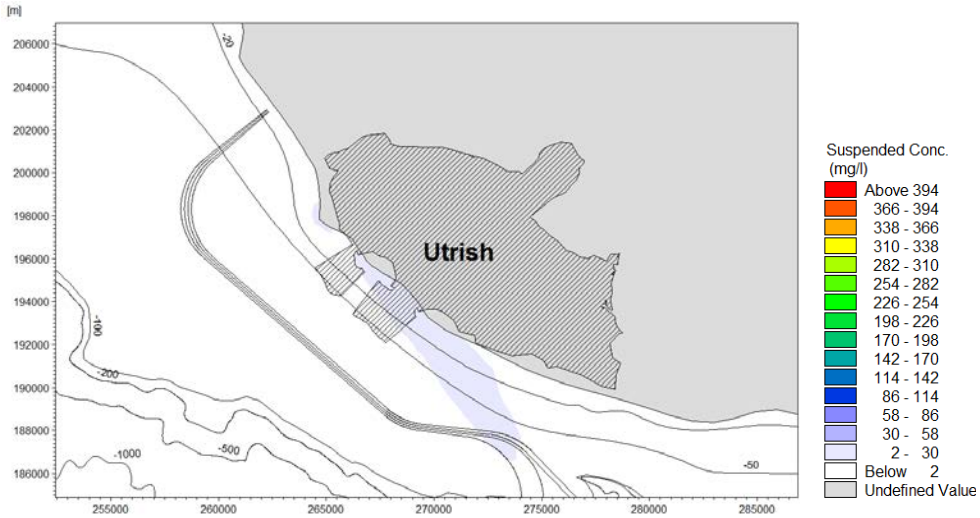


84 Hours

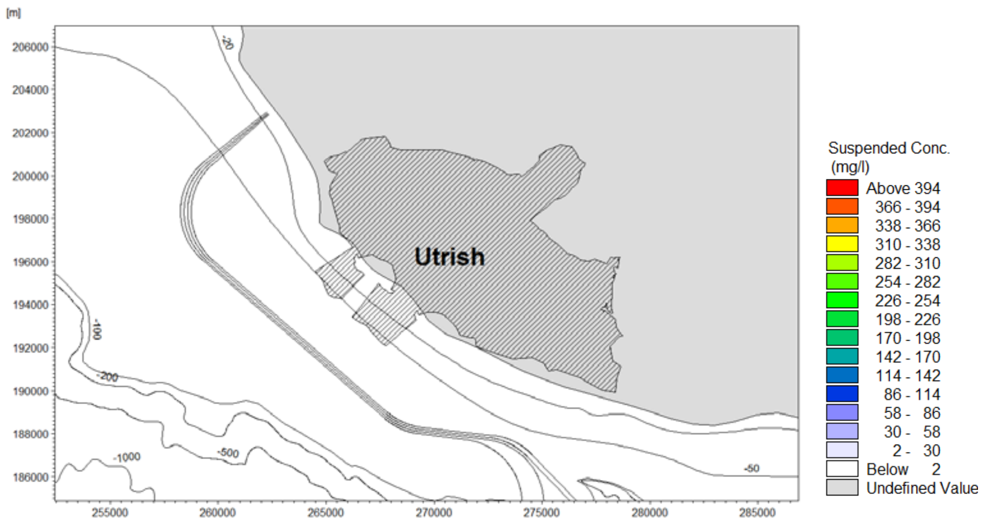
Figure 3-3b Plume Development under Clockwise Currents (Scenario 1)



96 Hours

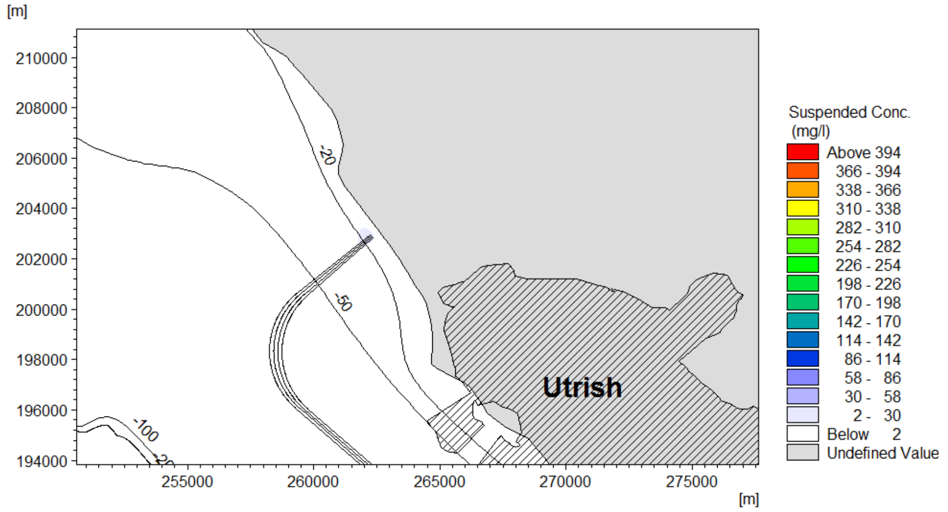


108 Hours

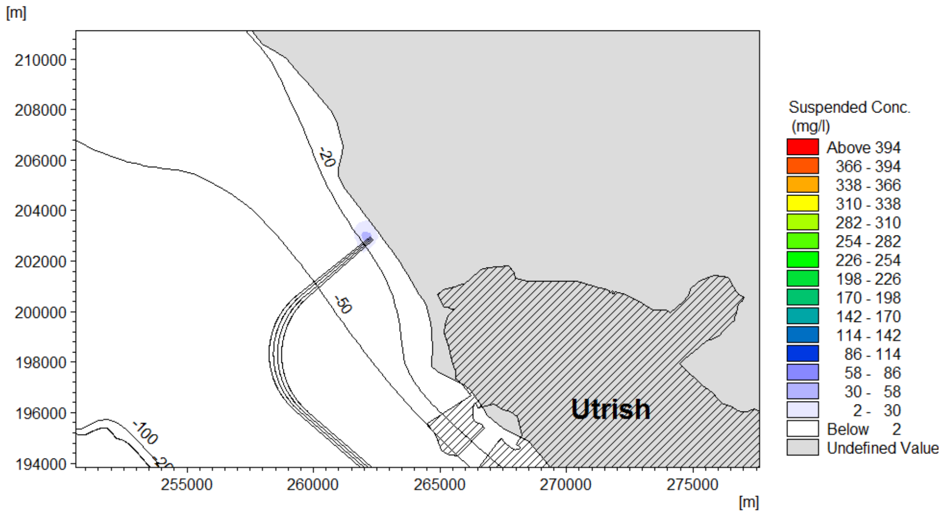


120 Hours

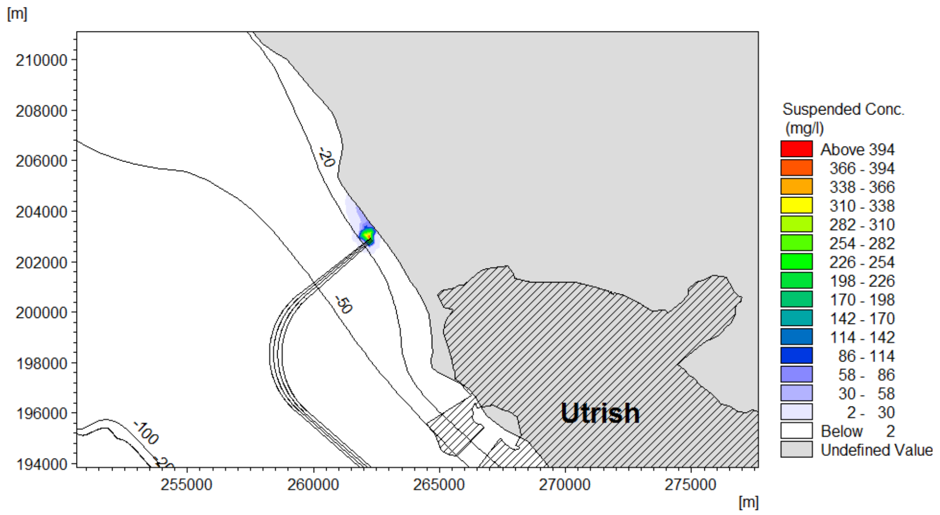
Figure 3-3c Plume Development under Clockwise Currents (Scenario 1)



Initial

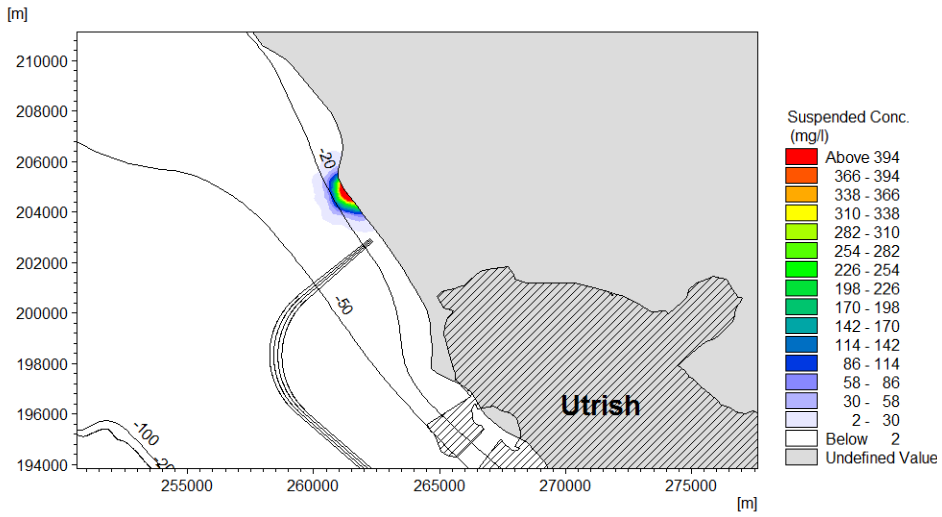


12 Hours

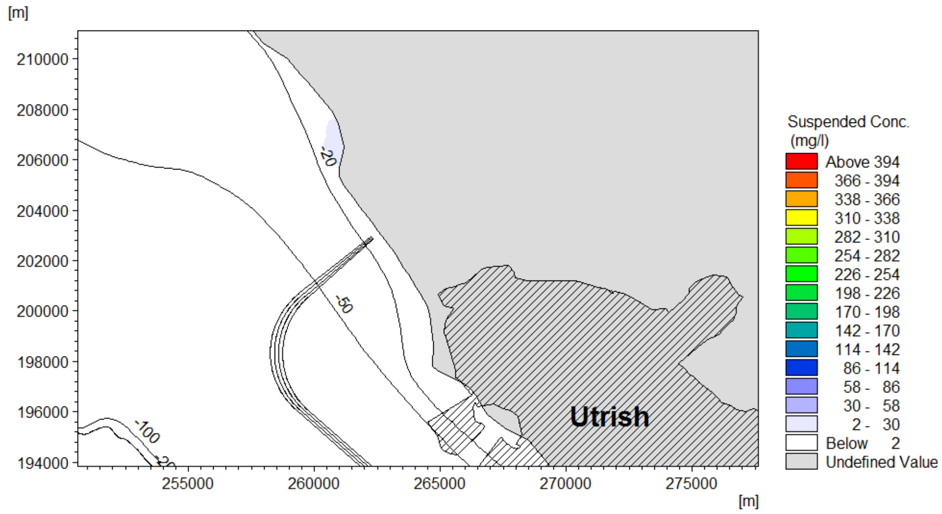


24 Hours

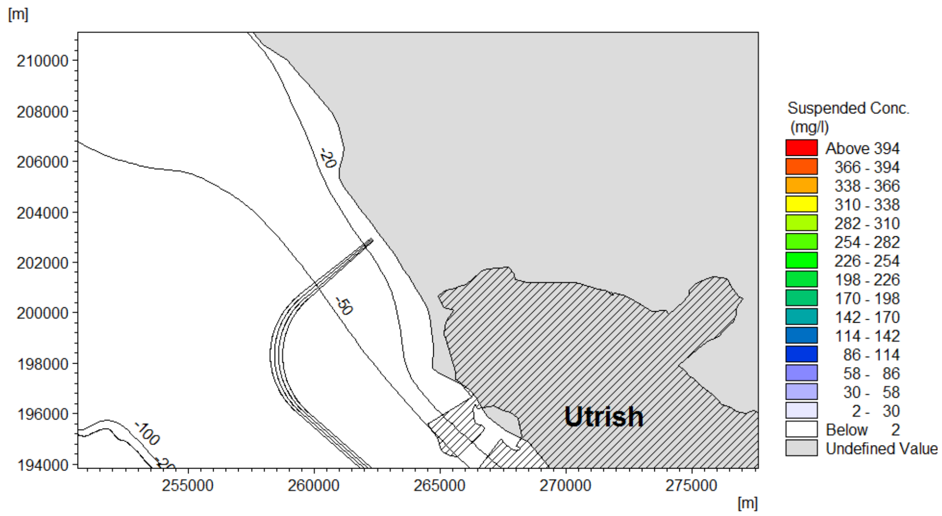
Figure 3-4a Plume Development under Clockwise Currents (Scenario 2)



36 Hours



48 Hours



60 Hours

Figure 3-4b Plume Development under Clockwise Currents (Scenario 2)

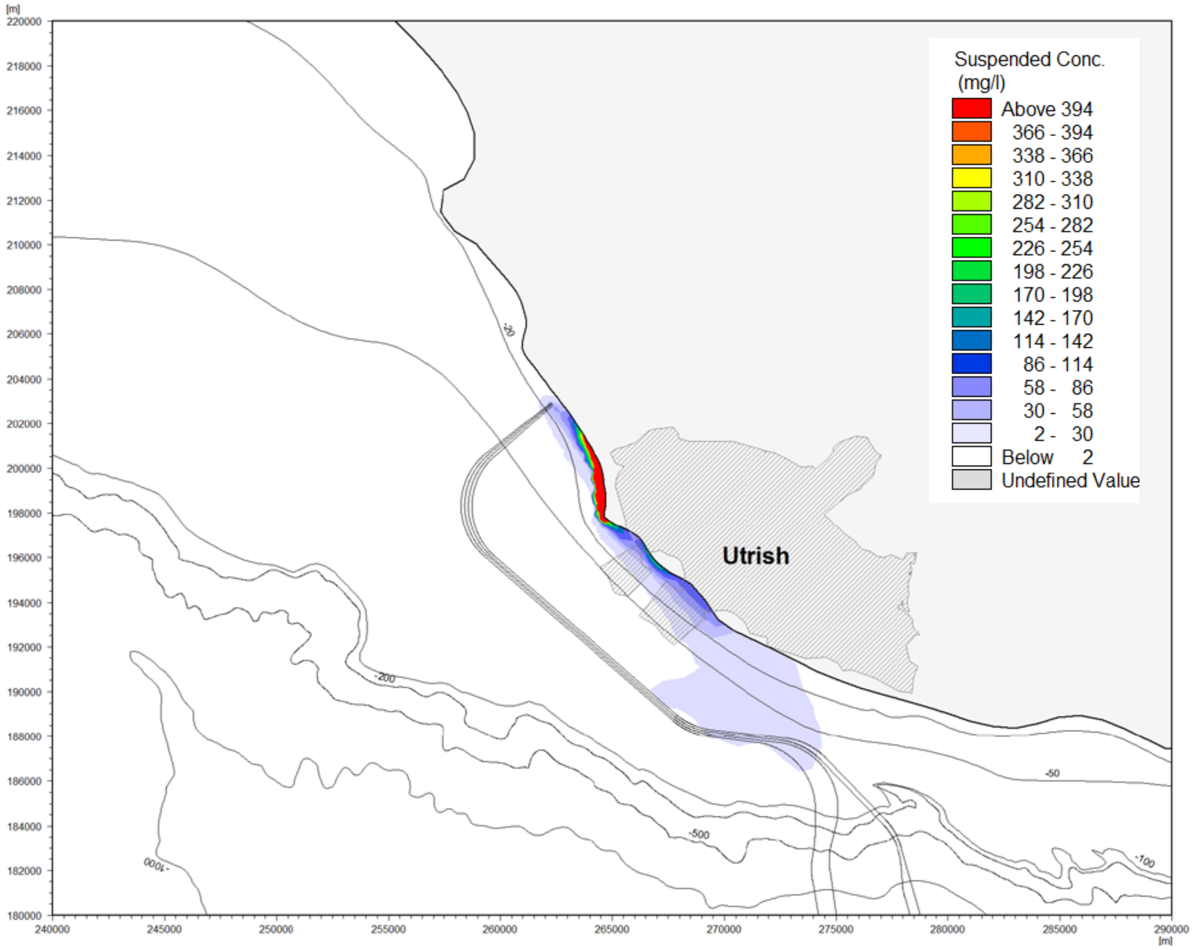


Figure 3-5 Maximum Plume Extent (Scenario 1)

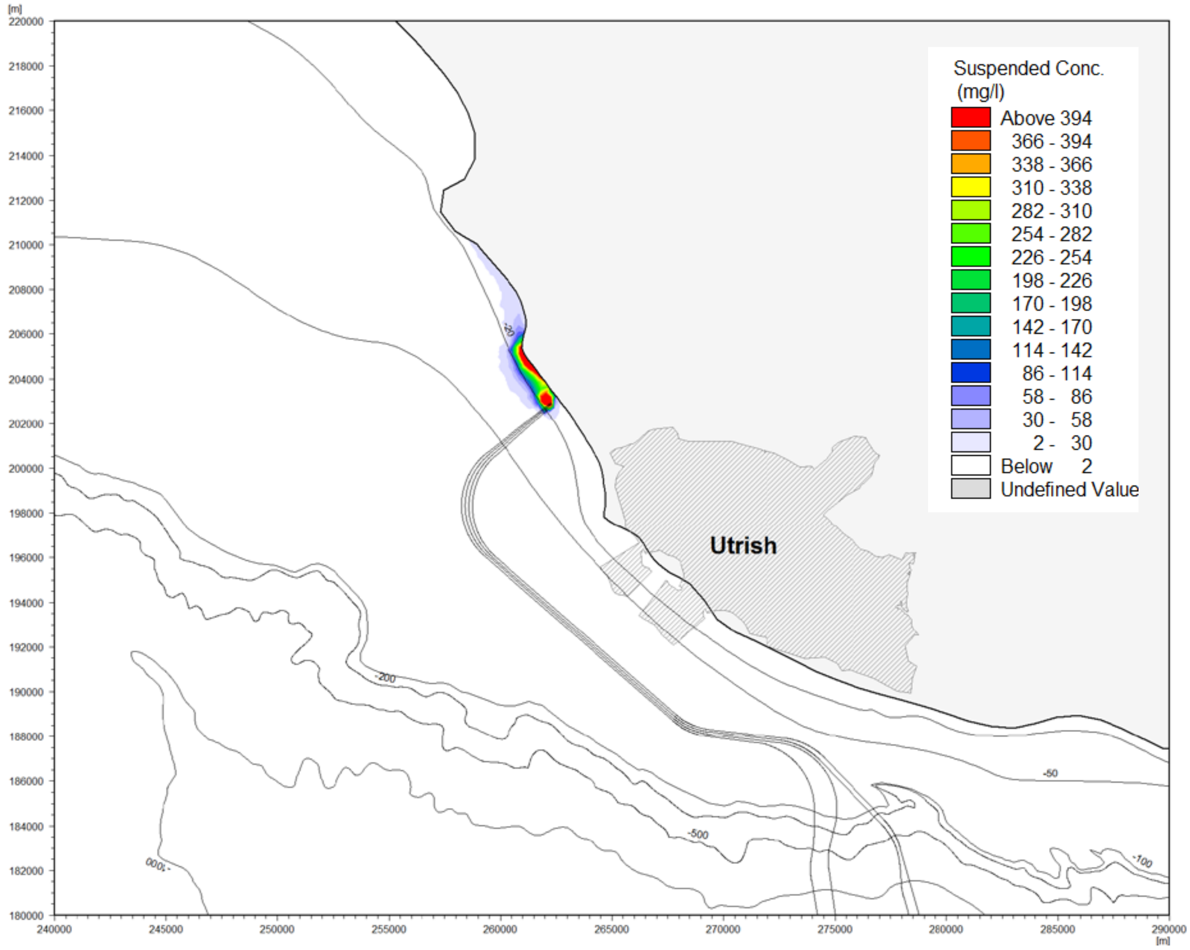


Figure 3-6 Maximum Plume Extent (Scenario 2)

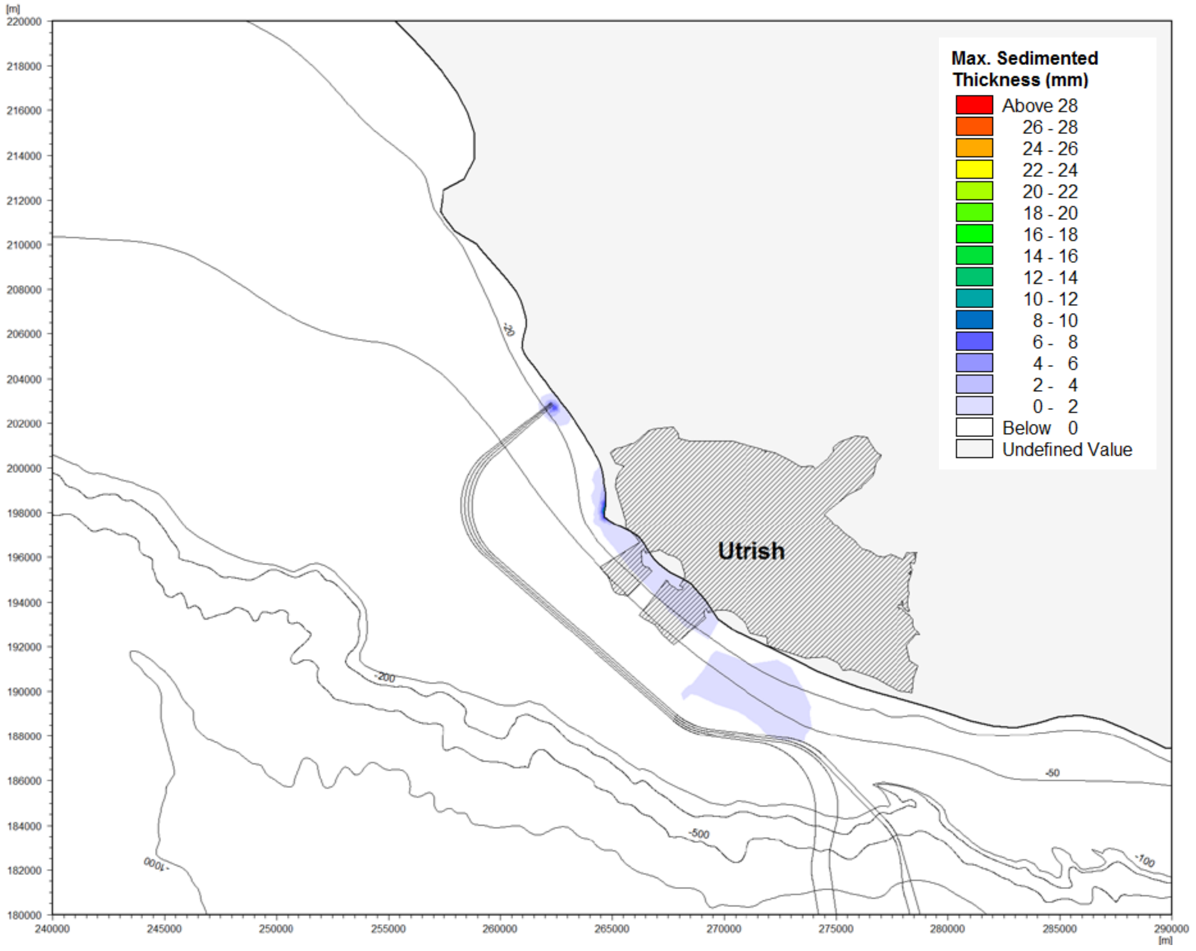


Figure 3-7 Maximum Sediment Thickness (Scenario 1)

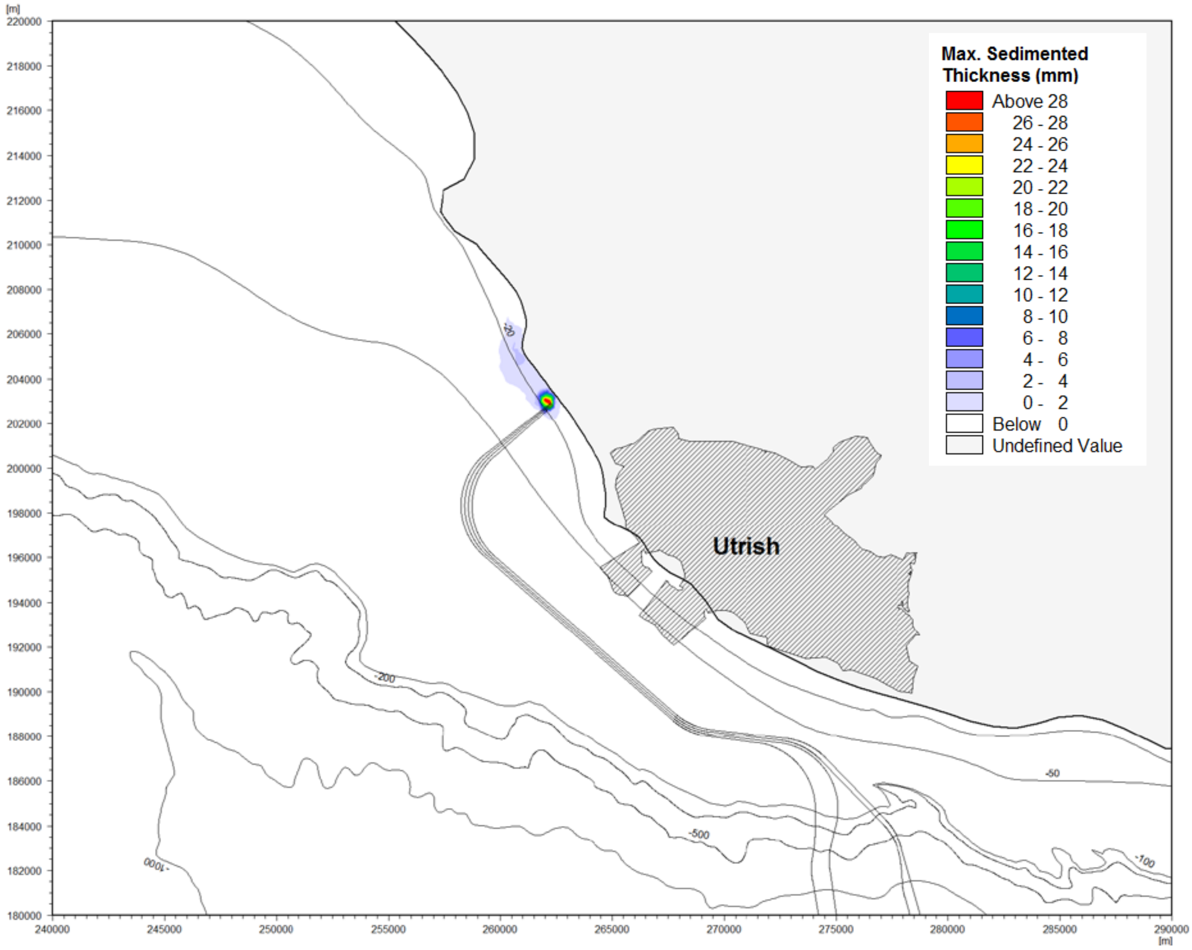


Figure 3-8 Maximum Sediment Thickness (Scenario 2)

Table 3.3 Distance and Area Affected by the Plume

Scenario		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
1	distance (km)	13.1	15.0	16.5	18.3	20.0	23.6
	area (km^2)	6.3	12.3	16.2	22.0	40.0	59.7
2	distance (km)	4.0	6.2	7.6	8.0	8.1	8.3
	area (km^2)	3.4	4.4	5.3	5.9	7.0	7.8

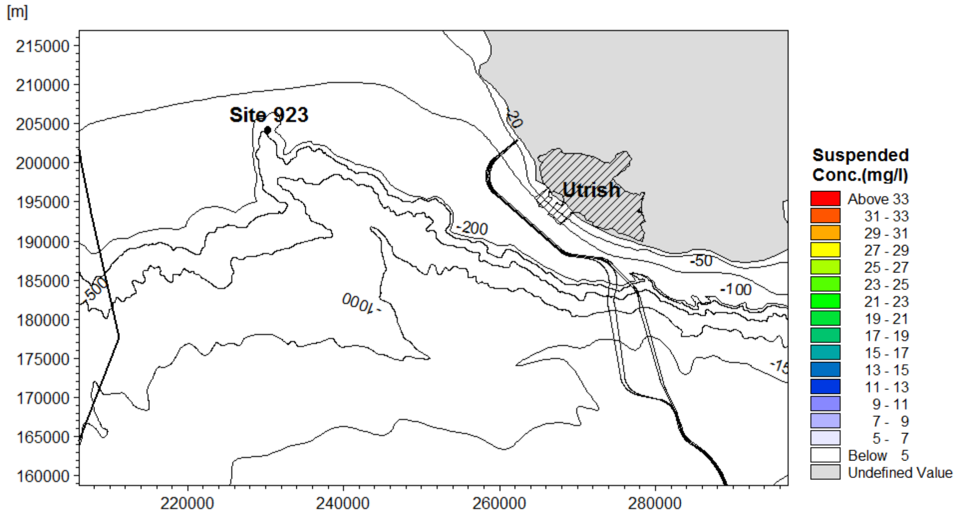
3.2.2 Pre-lay Dredging / Dumping on the Russian Slope

This section considers the dredging for the pre-lay trenching operations. The operations include multiple journeys between the proposed dredging and disposal sites. The model provides the concentrations at the surface, near bed and average values for the entire water column.

The representative snapshots of the bottom plume (>5mg/l) development for pre-lay dredging on the Russian slope are shown in Figures 3-9 and 3-10. On the Russian slope, a large plume area develops under the two current directions. The visible extents of the predicted sediment plume are indicated by the areas where the sediment concentration is greater than 5mg/l. For the modelled scenarios the plume develops during operations and follows the direction of the ambient currents. In general, the sediment plumes generated during dredging are confined to the alignment of the current directions. The presence of the plume can be expected to persist for 3-4 days after the dredging activity has stopped and will gradually dissipate thereafter.

Figures 3-11 to 3-16 illustrate the map plots of maximum concentration over 15 days in which the threshold is 2mg/l and 5mg/l (bottom). These plots show the spreading of the suspended sediment. The recorded maximum concentrations are 5.0mg/l at surface, 52mg/l at the bottom and 5.6mg/l as an average over the depth. Tables 3-4, 3-5 and 3-6 summarize the maximum affected area and distance from the dredging / dumping point to the contour defined by a given threshold concentration.

At the surface the plume will be barely visible. Close to the seabed, the sediment plume will be much larger. Sediment plumes are expected to disperse close to the seabed, undergoing cycles of settlement and resuspension due to the varying strength of the currents. The model shows that sediments will migrate and distribute near the seabed over a large area. The recorded maximum thickness is 1.5mm, as indicated in Figures 3-17 and 3-18.



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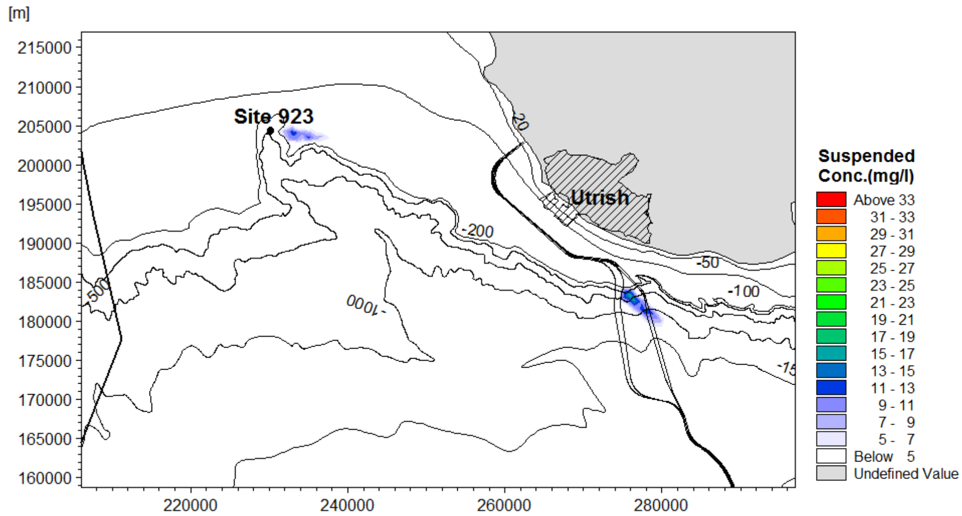
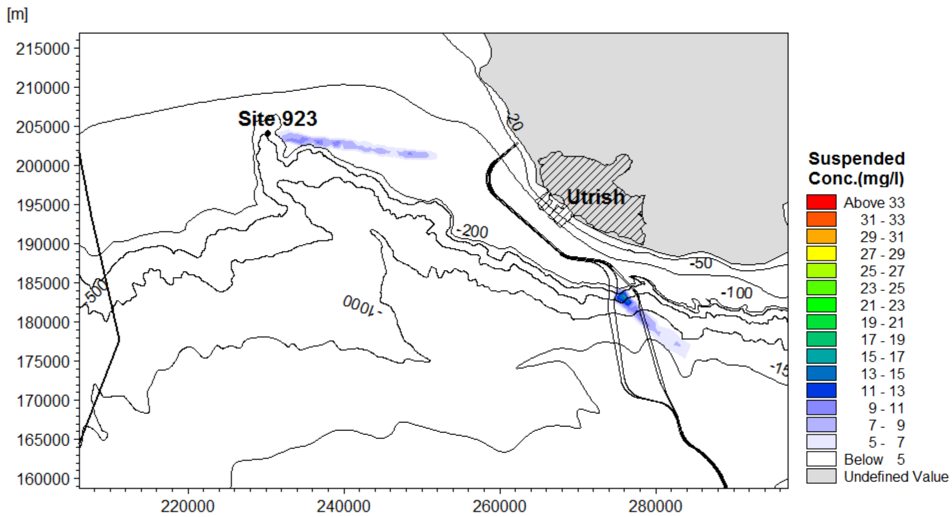
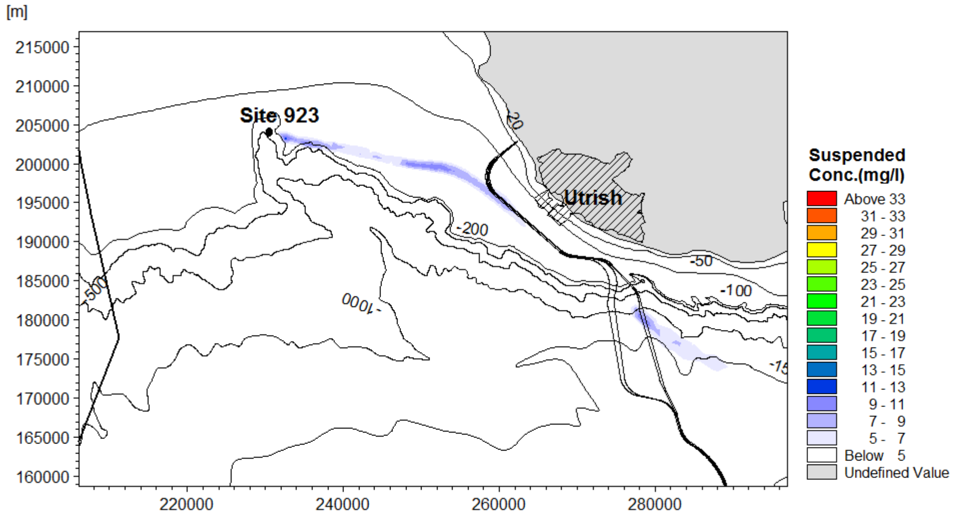


12 Hours

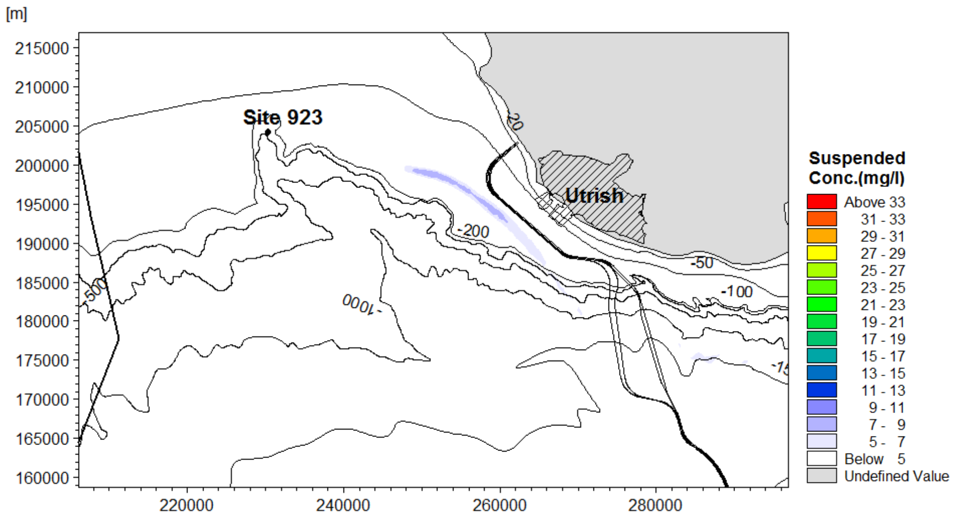


24 Hours

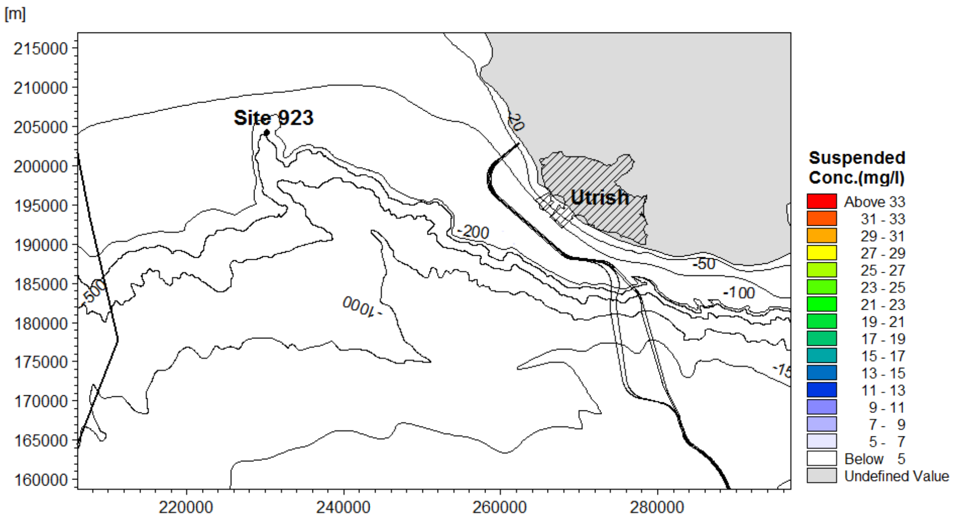
Figure 3-9a Plume Development under Clockwise Currents (Scenario 3)



36 Hours

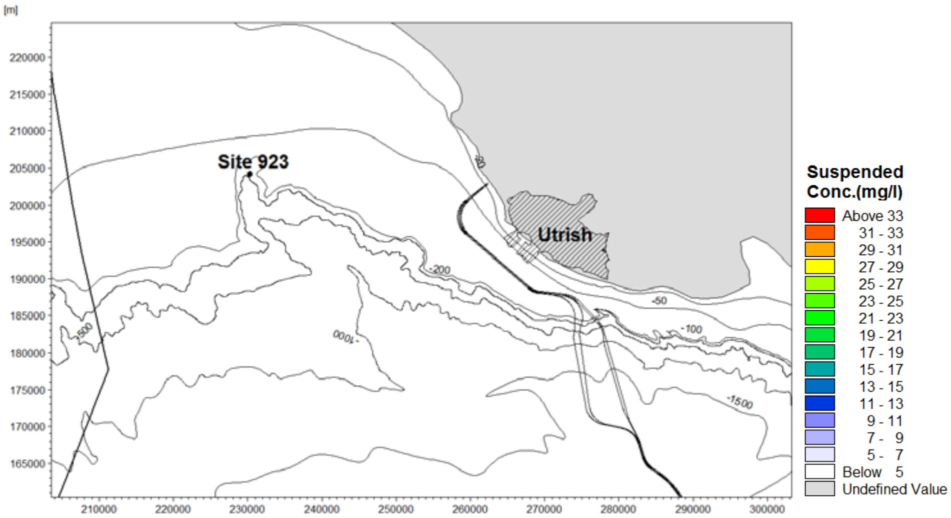


48 Hours

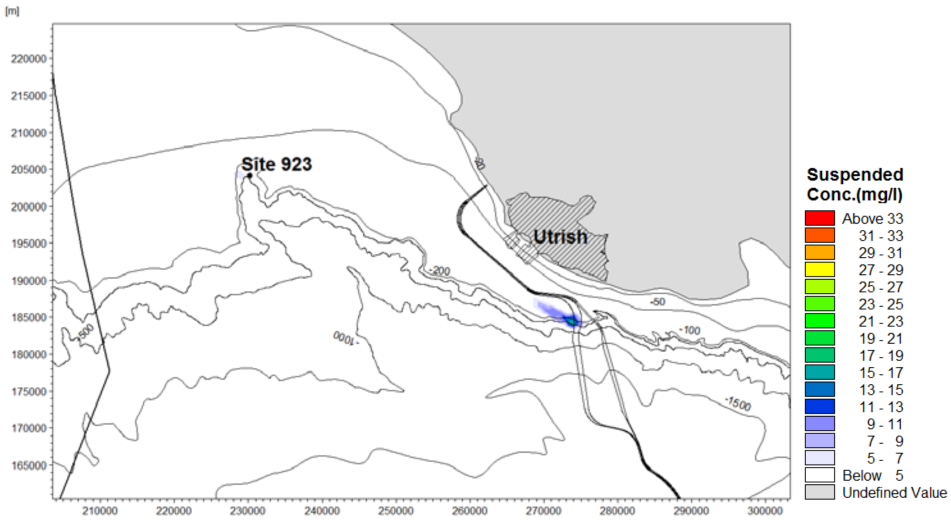


60 Hours

Figure 3-9b Plume Development under Clockwise Currents (Scenario 3)



Initial



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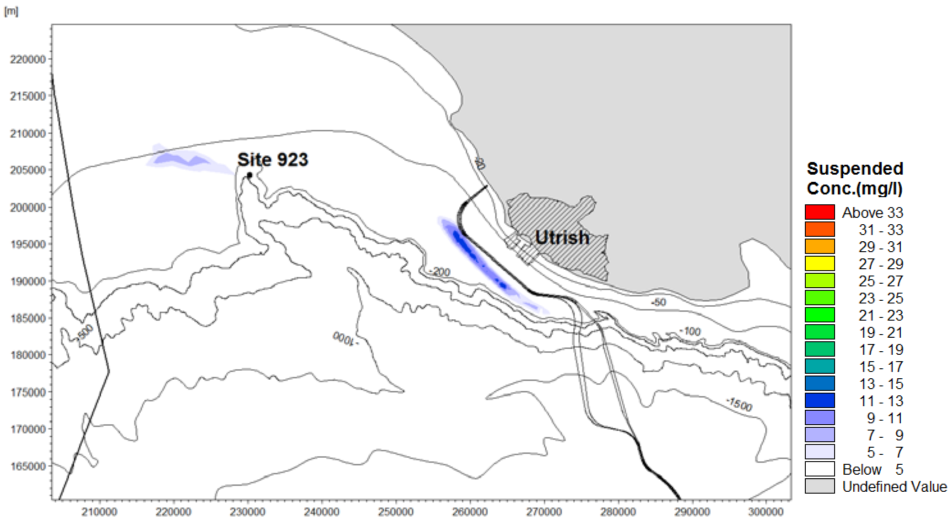
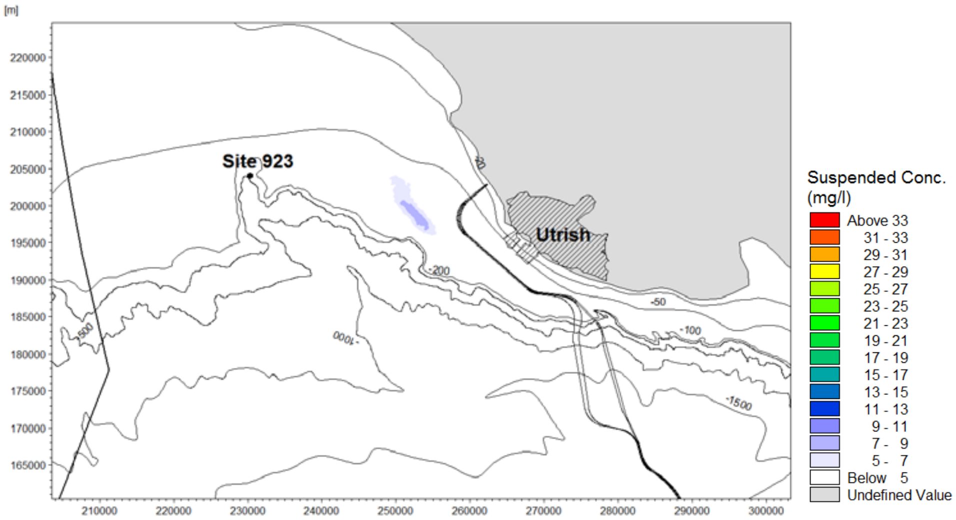
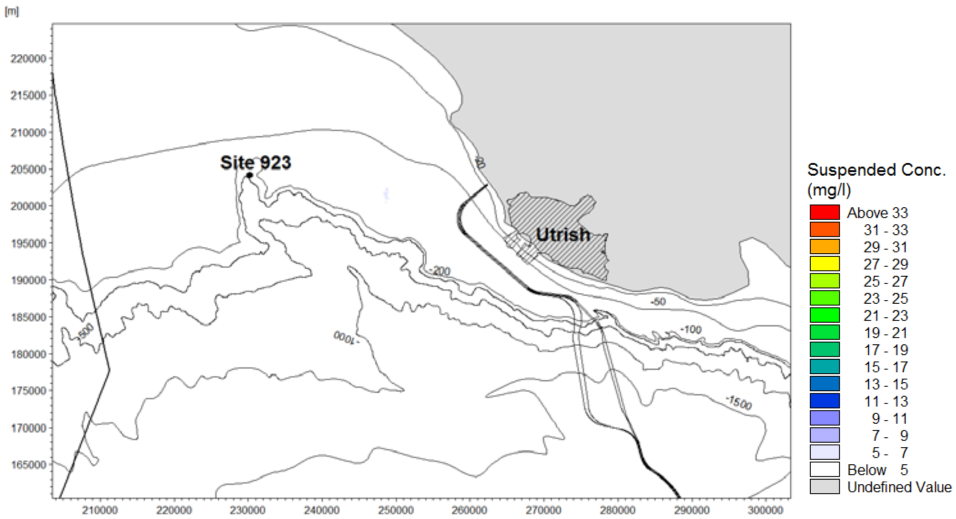


36 Hours

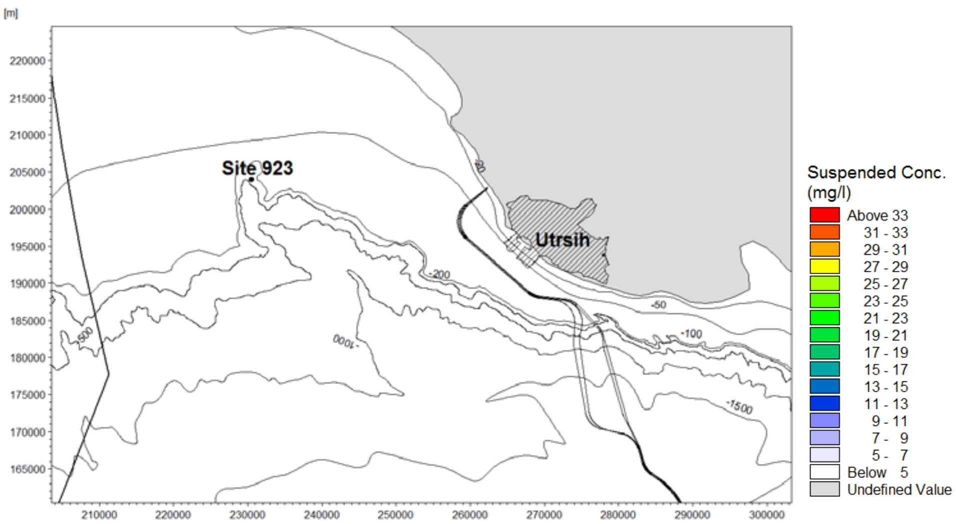
Figure 3-10a Plume Development under Counter-Clockwise Currents (Scenario 4)



60 Hours



72 Hours



84 Hours

Figure 3-10b Plume Development under Counter-Clockwise Currents (Scenario 4)

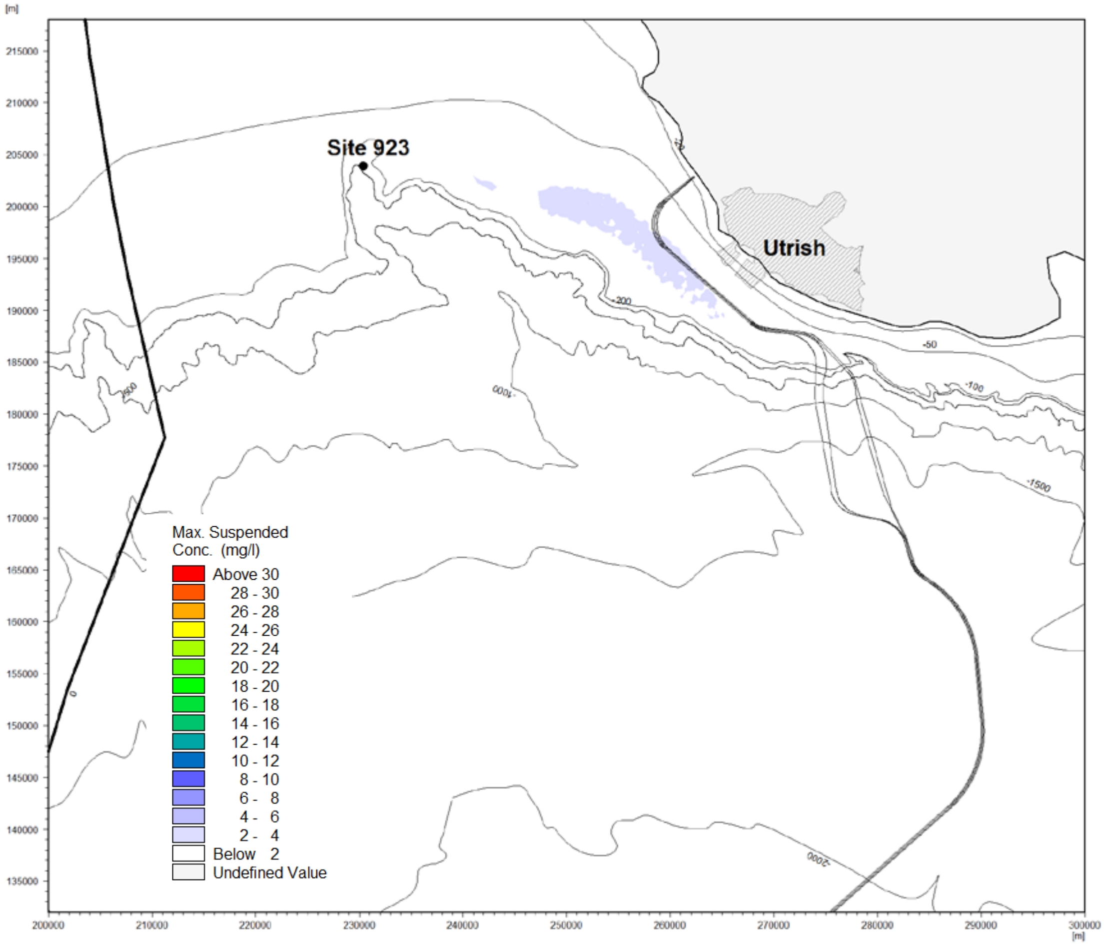


Figure 3-11 Maximum Surface Plume Extent (Scenario 3)

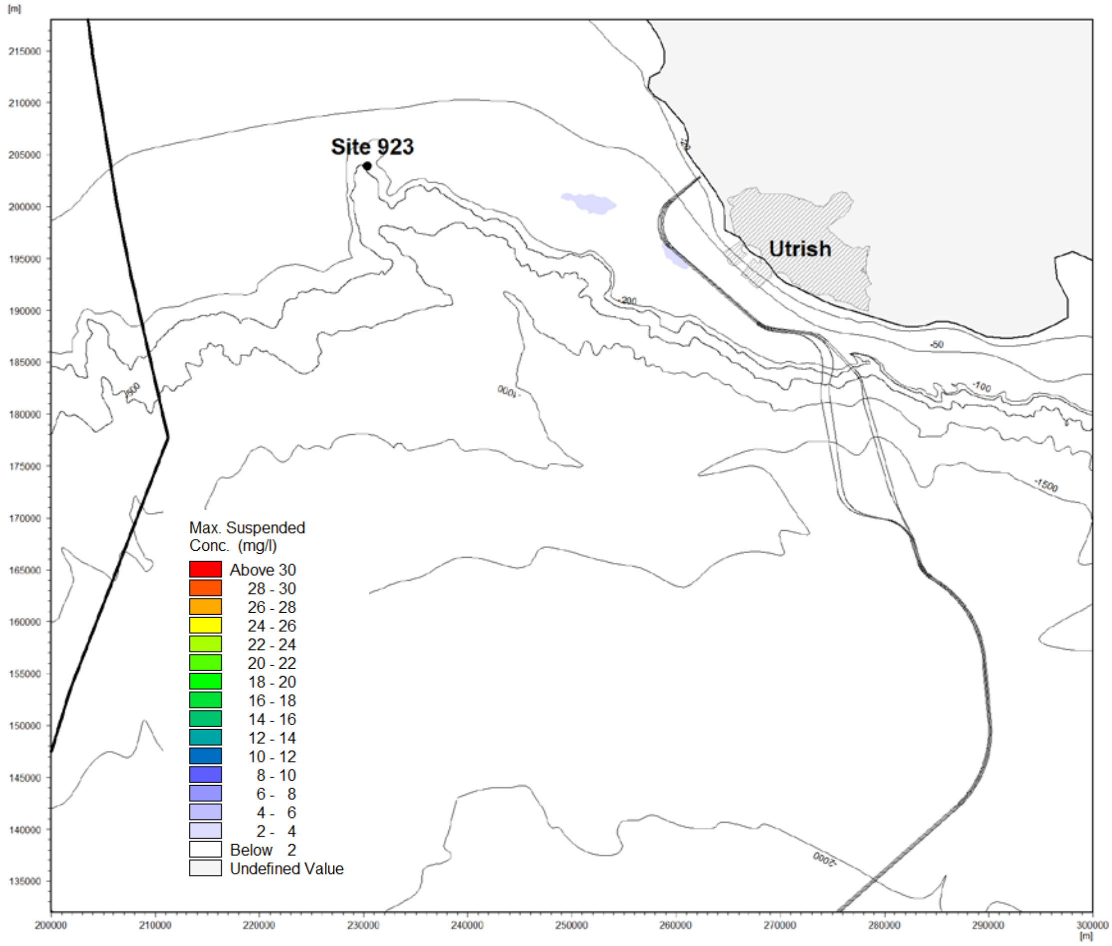


Figure 3-12 Maximum Depth-averaged Plume Extent (Scenario 3)

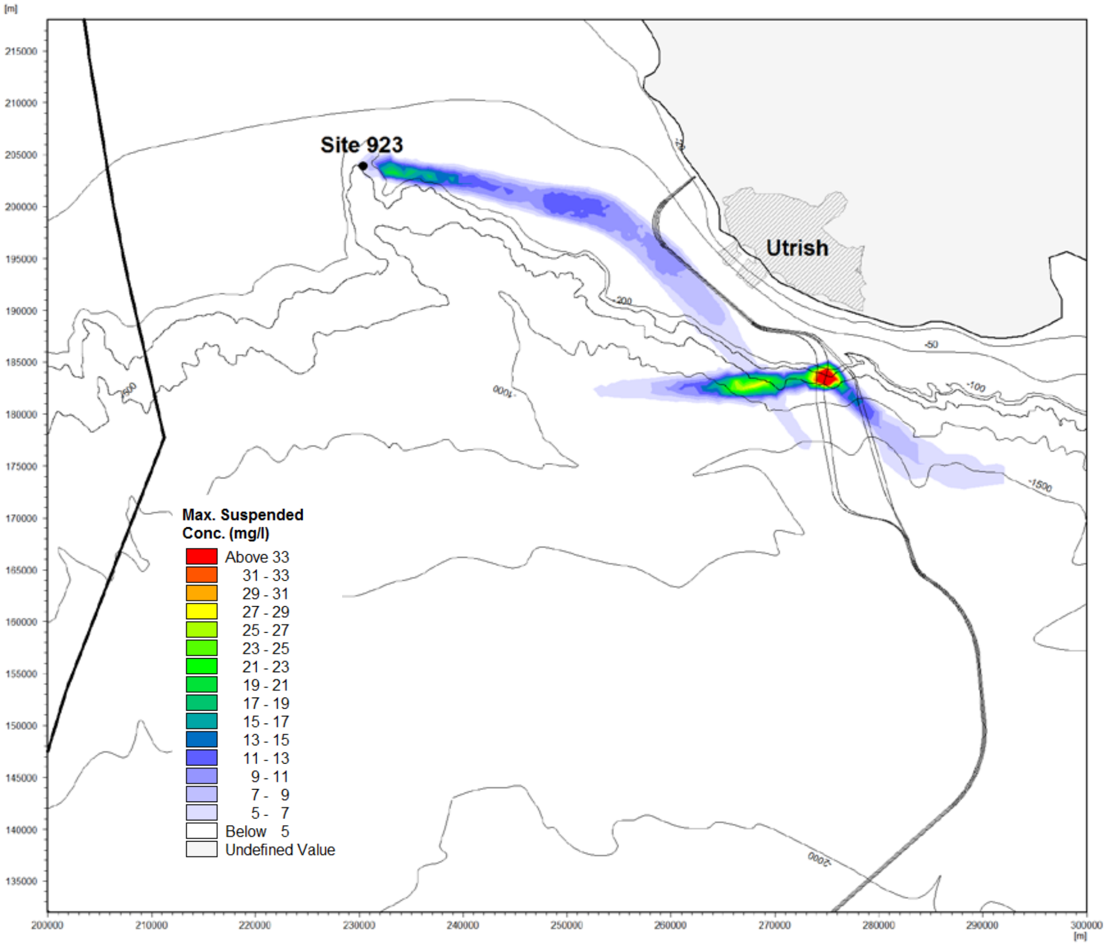


Figure 3-13 Maximum Bottom Plume Extent (Scenario 3)

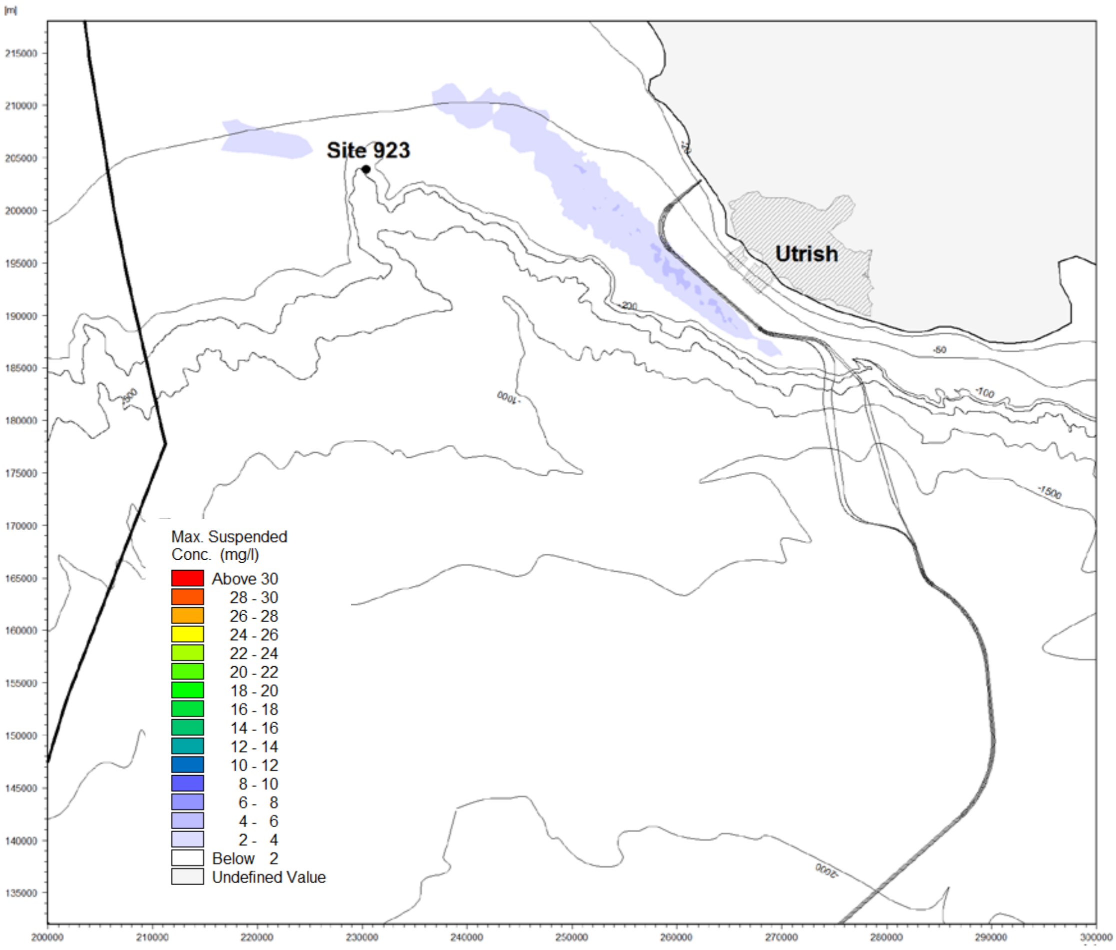


Figure 3-14 Maximum Surface Plume Extent (Scenario 4)

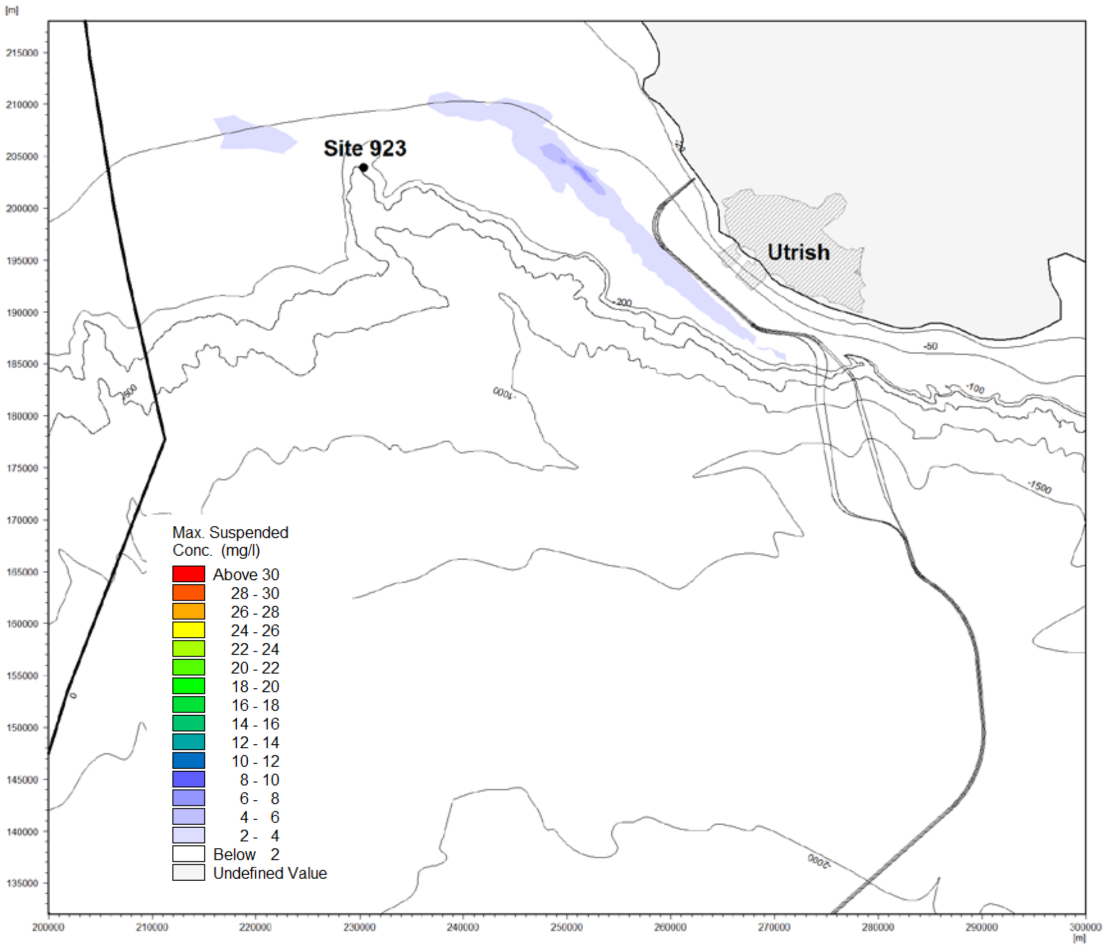


Figure 3-15 Maximum Depth-averaged Plume Extent (Scenario 4)

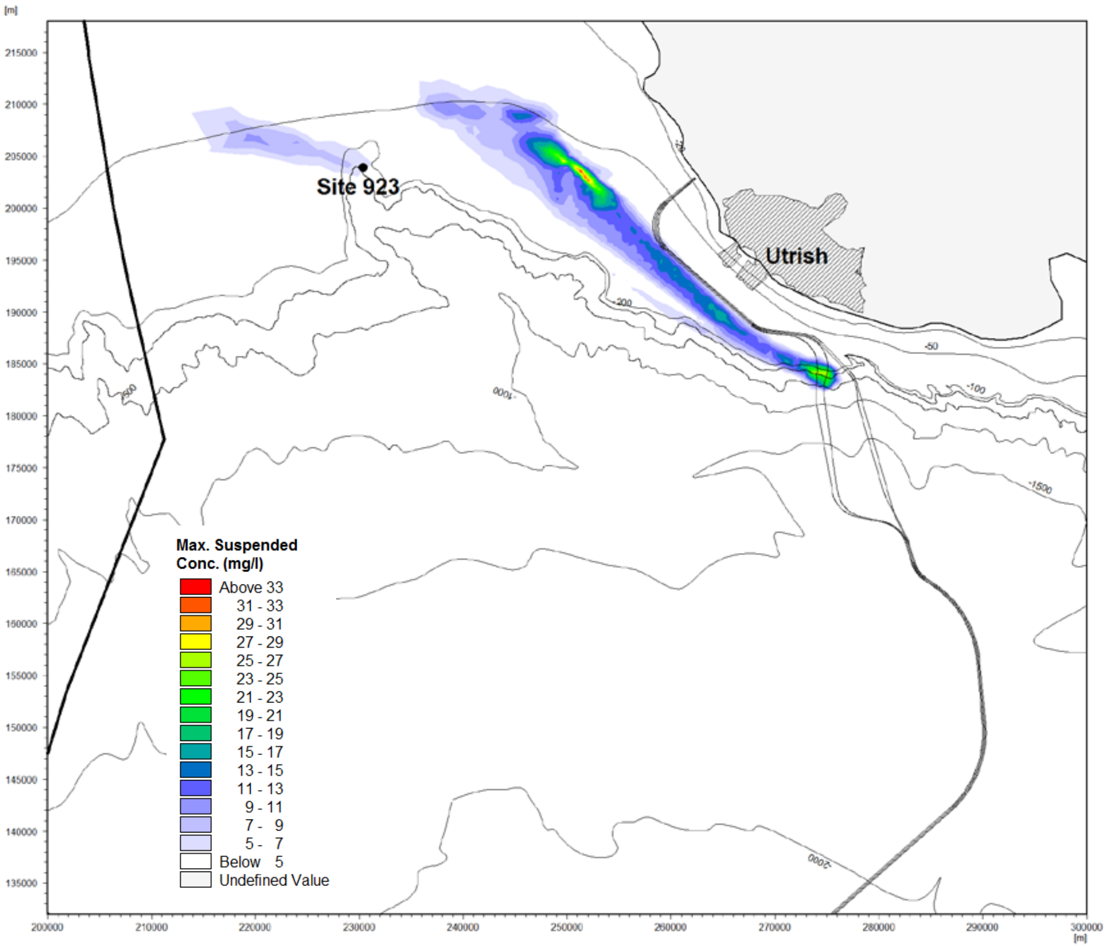


Figure 3-16 Maximum Bottom Plume Extent (Scenario 4)

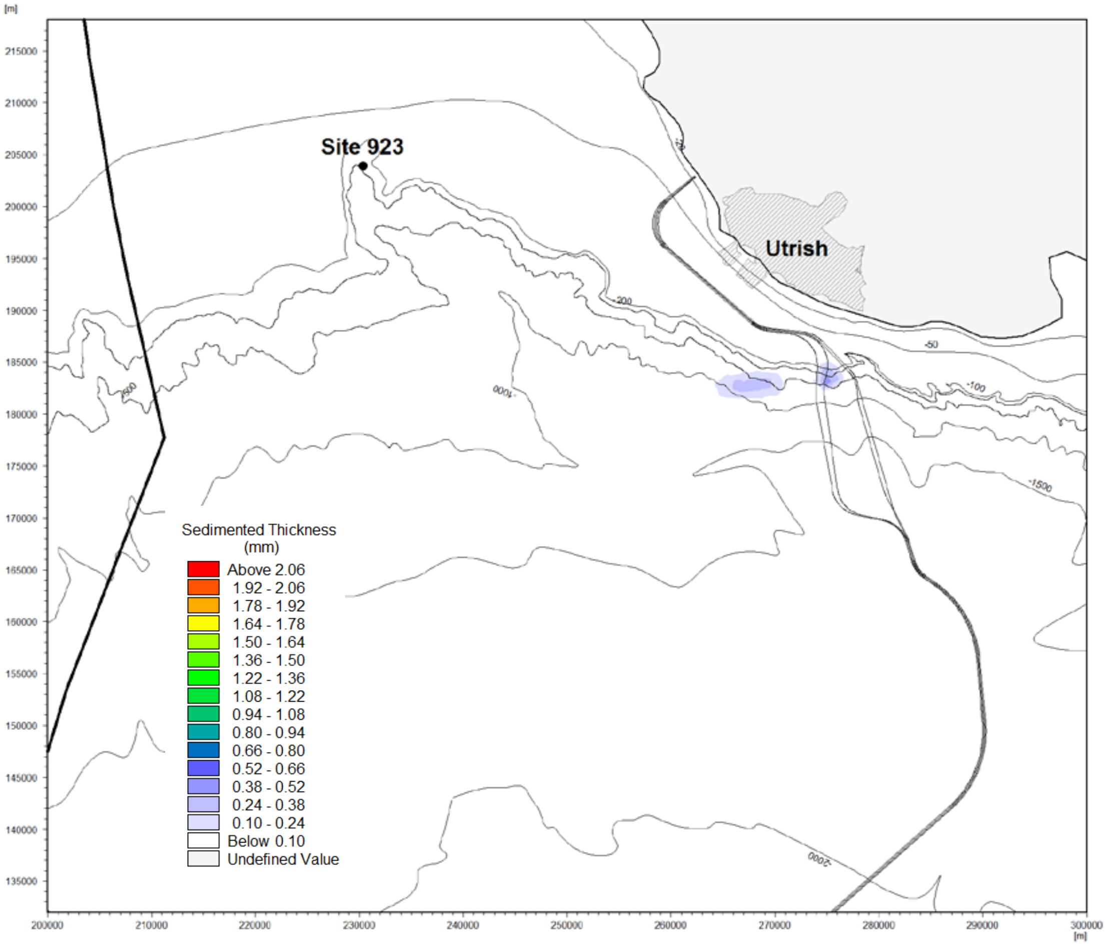


Figure 3-17 Maximum Sediment Thickness (Scenario 3)

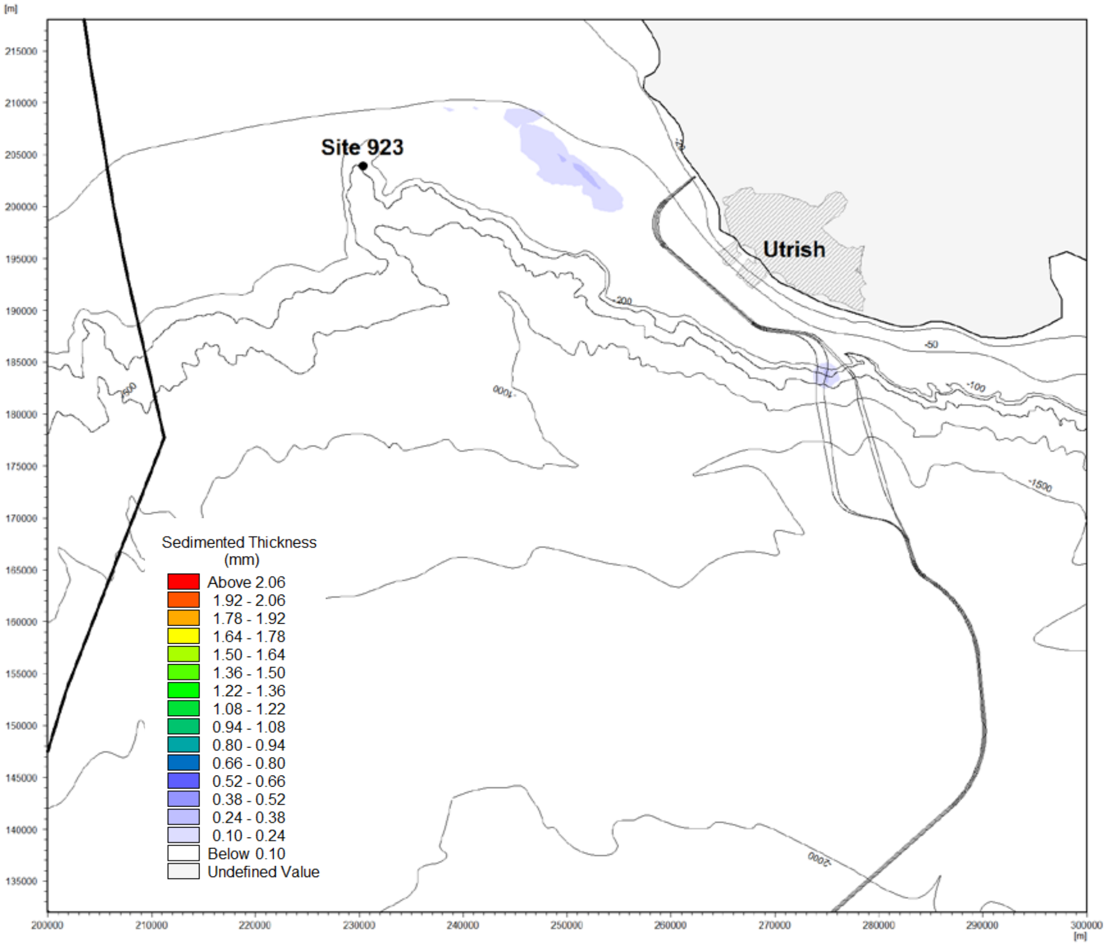


Figure 3-18 Maximum Sediment Thickness (Scenario 4)

Table 3-4 Distance and Area Affected by Plume at Surface Layer (pre-lay)

Scenarios		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
3	distance (km)					30.5	40.0
	area (km^2)					53.4	121.4
4	distance (km)				2.5	41.0	50.0
	area (km^2)				6.0	175.9	466.9

Table 3-5 Distance and Area Affected by Plume for Depth-averaged Conditions (pre-lay)

Scenarios		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
3	distance (km)					28.4	40.0
	area (km^2)					15.9	117.5
4	distance (km)				21.5	41.0	52.3
	area (km^2)				6.2	143.0	433.8

Table 3-6 Distance and Area Affected by Plume for Bottom Layer (pre-lay)

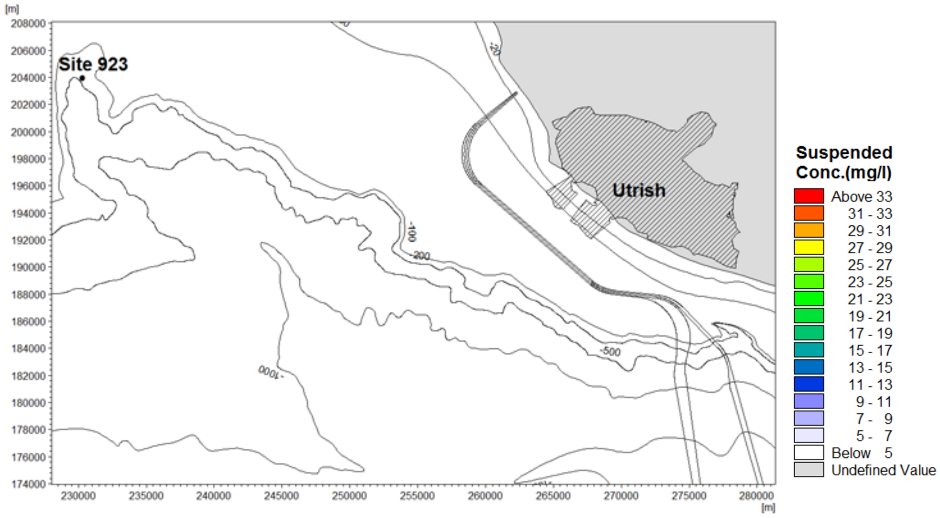
Scenarios		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
3	distance (km)	1.5	10.0	35.0	70.5	98.0	105.0
	area (km^2)	2.2	15.4	87.6	256.7	1531.9	3154.6
4	distance (km)	0.8	10.0	32.0	40.0	60.0	75.0
	area (km^2)	0.5	11.4	112.6	307.2	774.3	996.3

3.2.3 Post-lay Trenching Operation on the Shelf

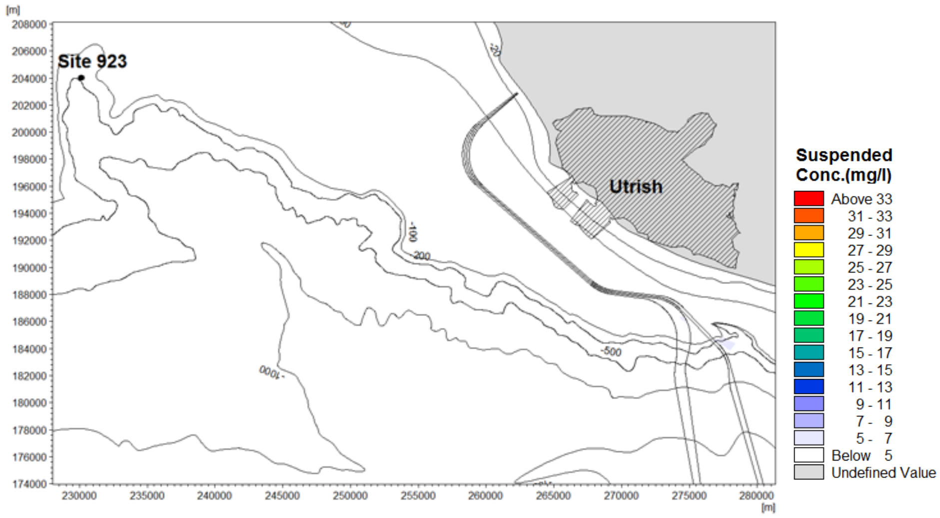
The modeling considered the dredging operation for the post-lay trenching operation. For this operation, the material is pushed aside from the pipeline path and no material will be picked up and deposited elsewhere.

The representative snapshots of the bottom plume (>5mg/l) development for post-lay dredging on the shelf are shown in Figures 3-19 and 3-20. The plume formed by the dredging operation is drifting in the direction and with the velocity of currents. A continuous plume at bottom defined by 5mg/l presents for about 2-3 days.

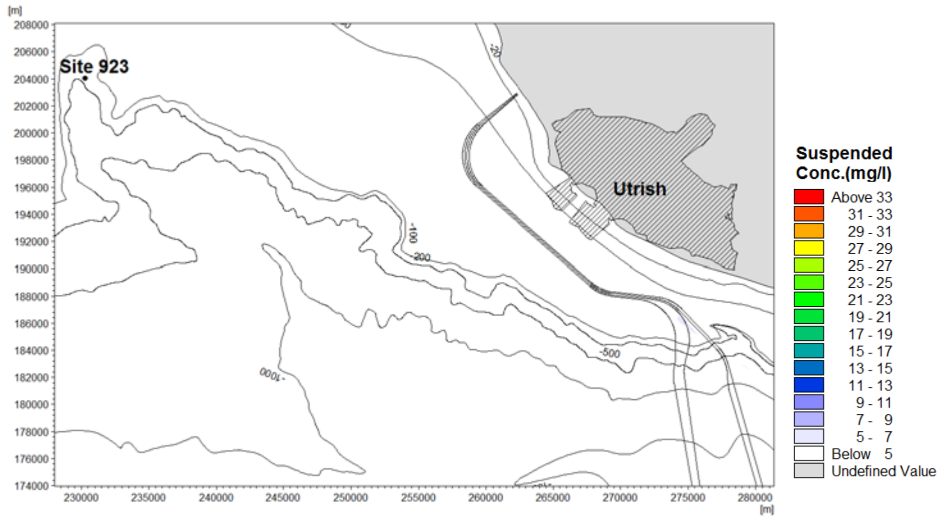
Figures 3-21 to 3-26 illustrate the plots of maximum concentration over 15 days defined by a threshold of 2mg/l and 5mg/l (bottom). The recorded maximum concentrations are 3.5mg/l at surface, 6.2mg/l (depth-averaged) and 25.0mg/l at bottom, respectively. The impacts of the dredging plume are summarised for six thresholds in Tables 3-7, 3-8 and 3-9. The thicknesses of deposited sediment for Scenarios 5 and 6 are shown in Figures 3-27 and 3-28. A maximum sediment thickness of only 0.3 mm was found for the material.



Initial

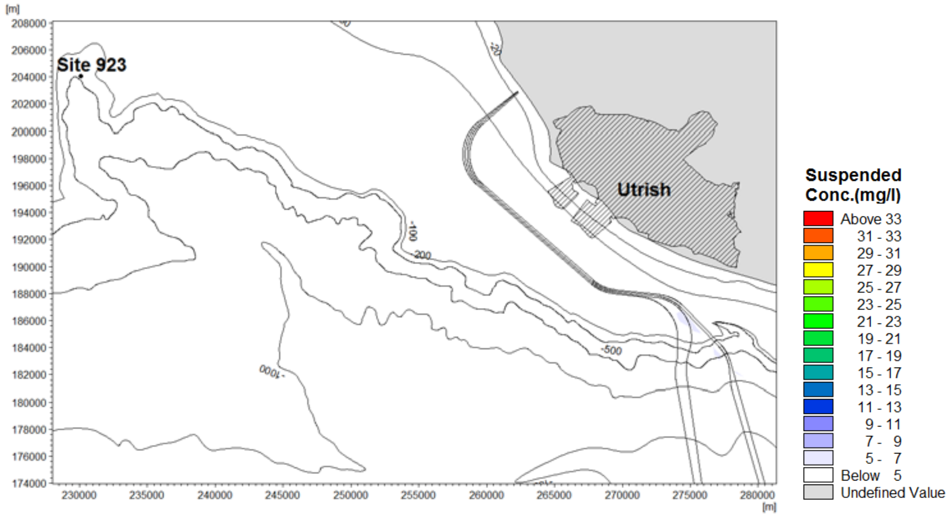


12 Hours

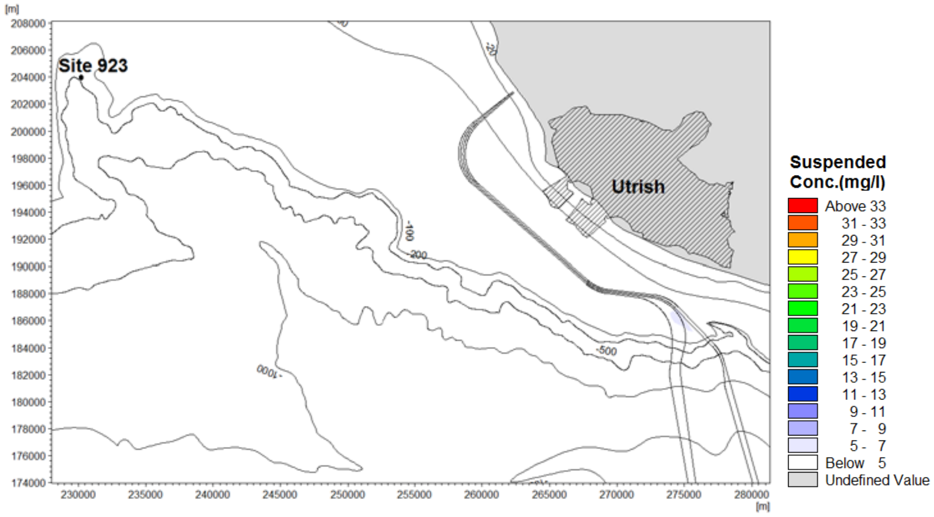


24 Hours

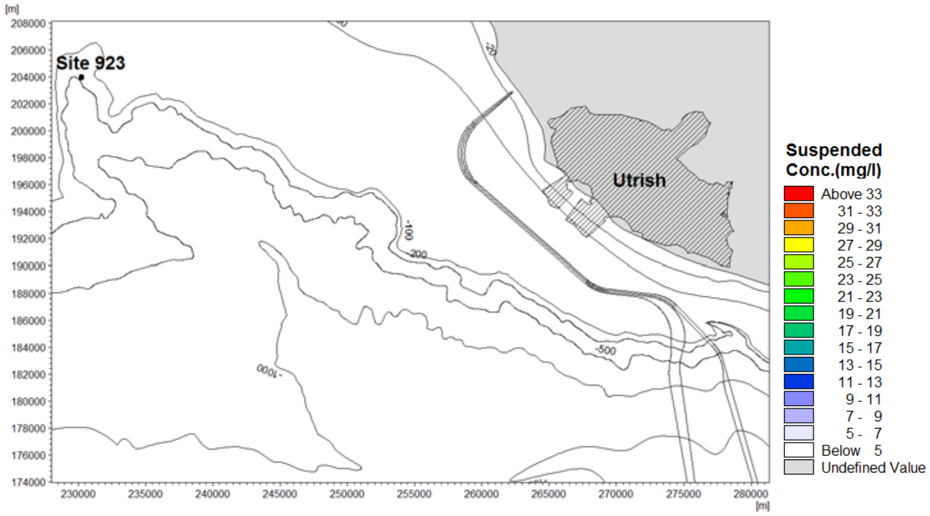
Figure 3-19a Plume Development under Clockwise Currents (Scenario 5)



36 Hours

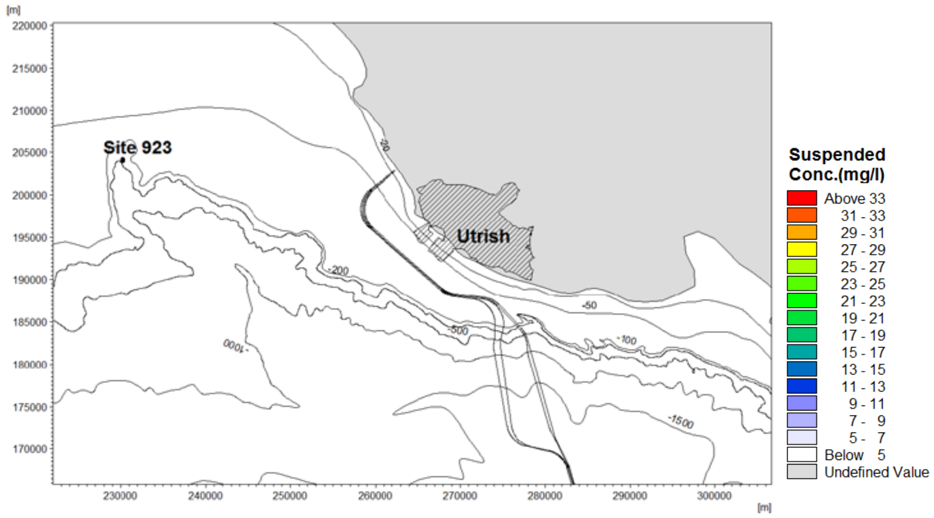


48 Hours

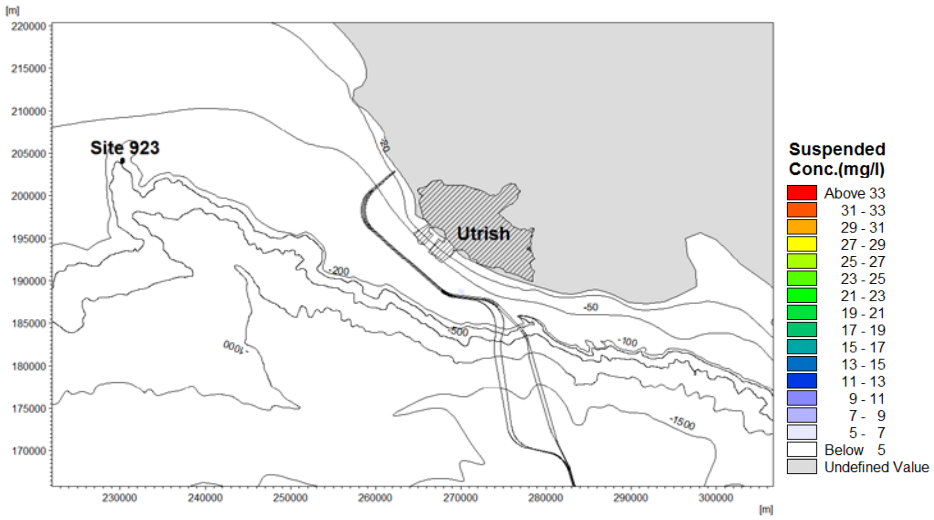


56 Hours

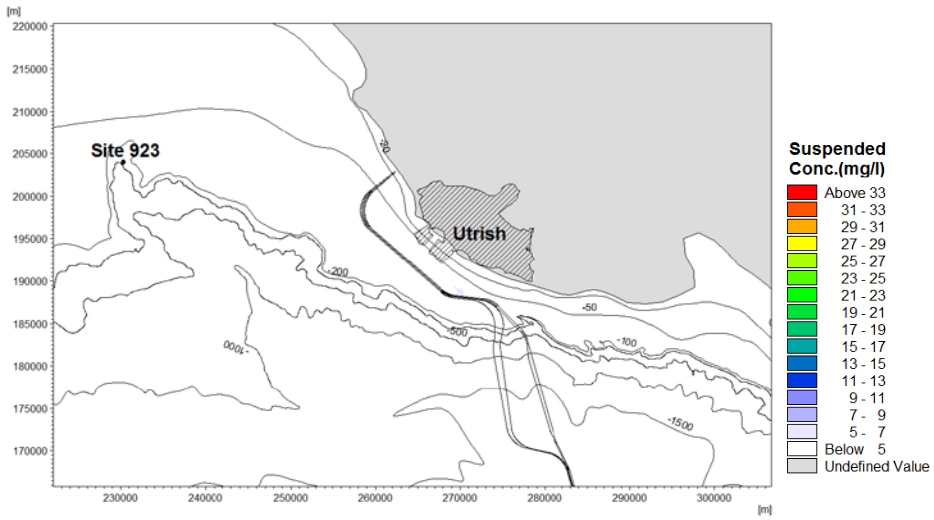
Figure 3-19b Plume Development under Clockwise Currents (Scenario 5)



Initial

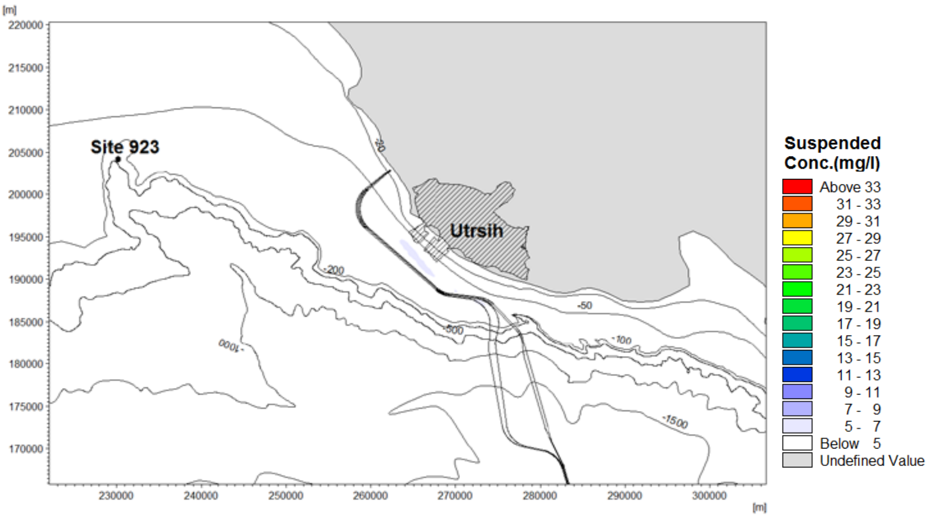


12 Hours

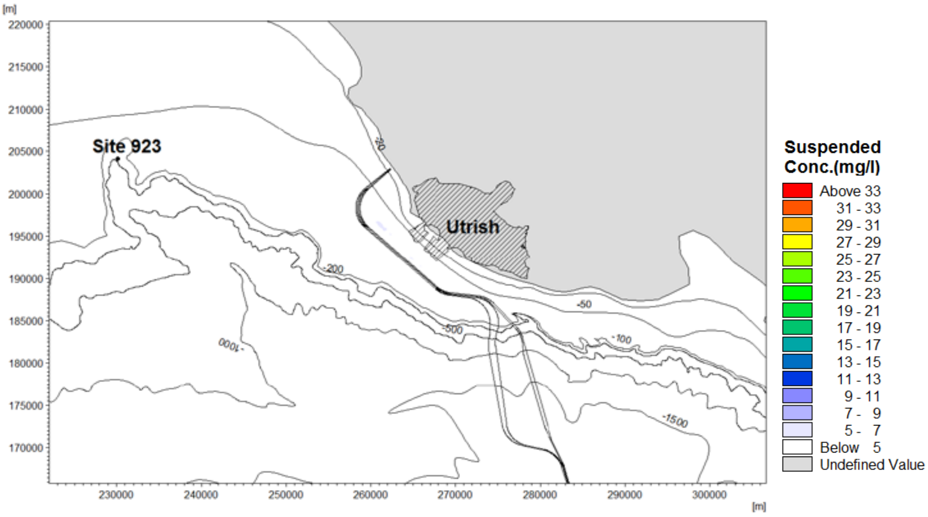


18 Hours

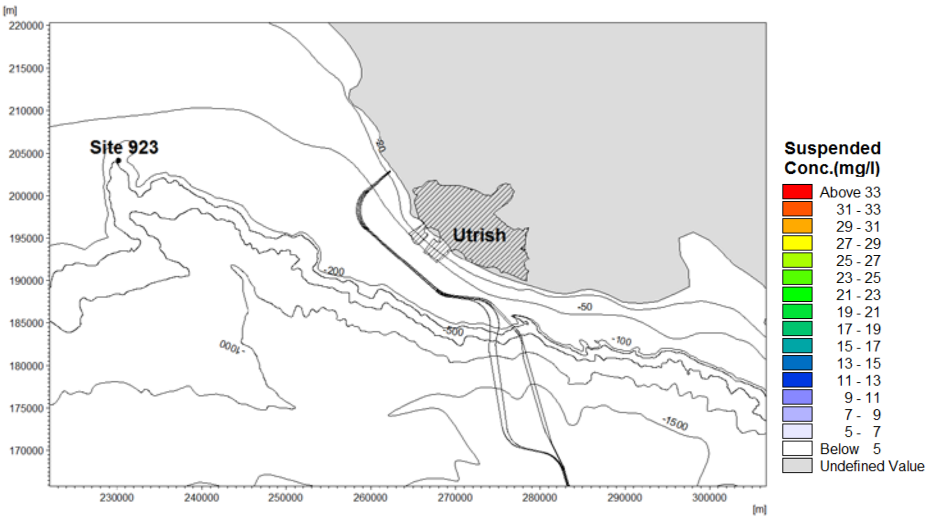
Figure 3-20a Plume Development under Counter-Clockwise Currents (Scenario 6)



30 Hours



36 Hours



48 Hours

Figure 3-20b Plume Development under Counter-Clockwise Currents (Scenario 6)

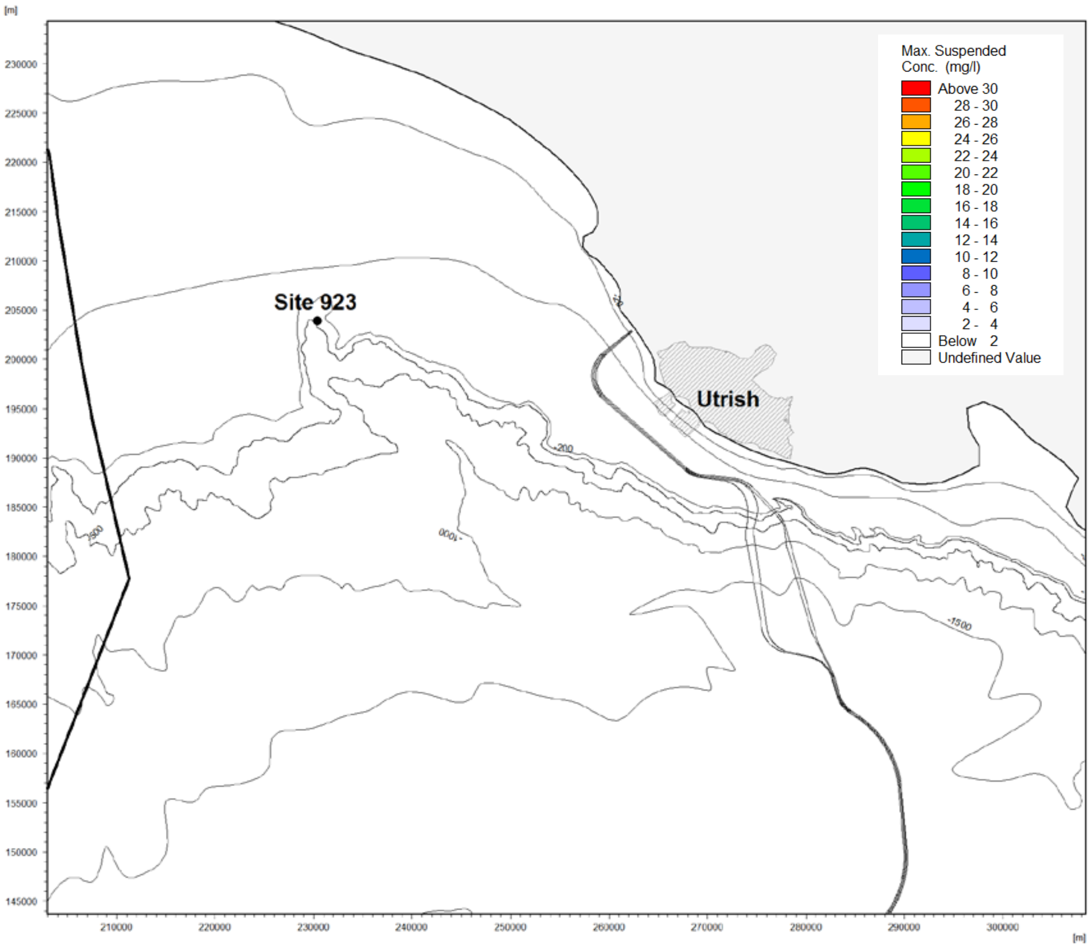


Figure 3-21 Maximum Surface Plume Extent (Scenario 5)

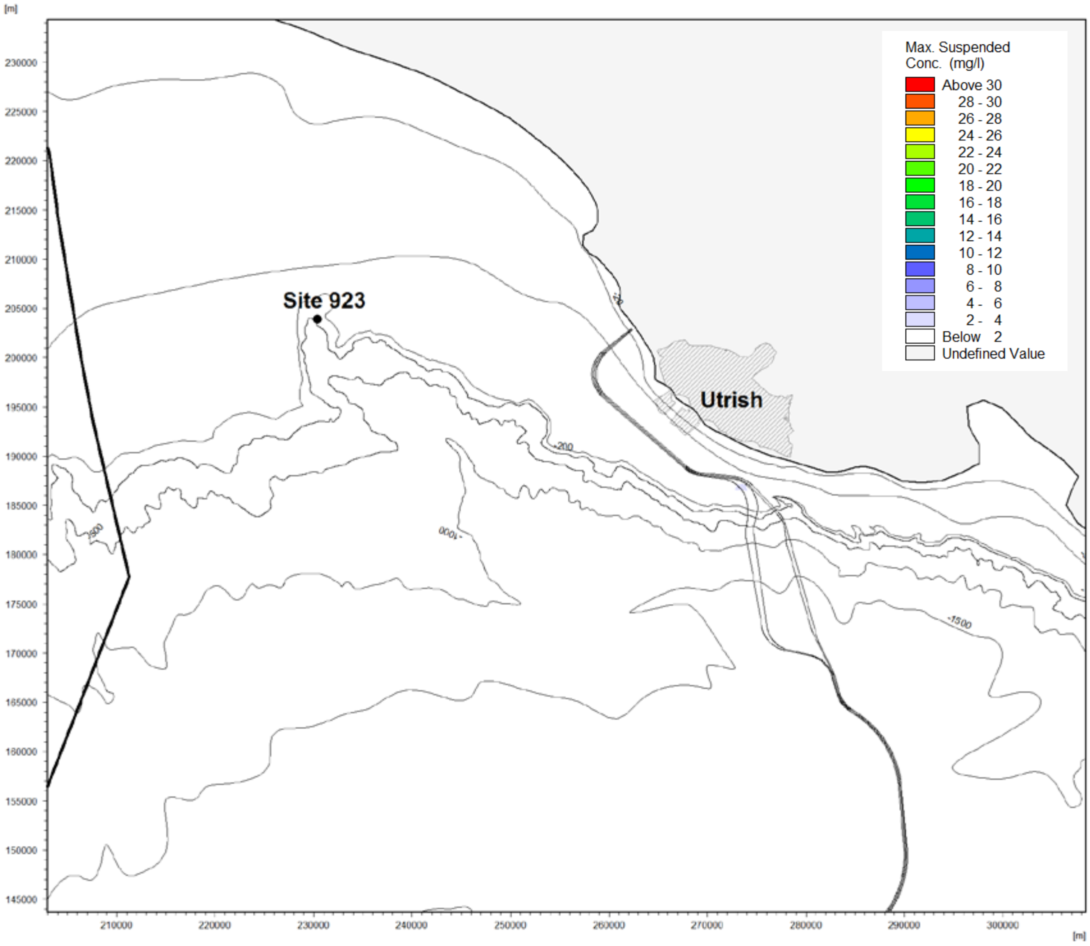


Figure 3-22 Maximum Depth-averaged Plume Extent (Scenario 5)

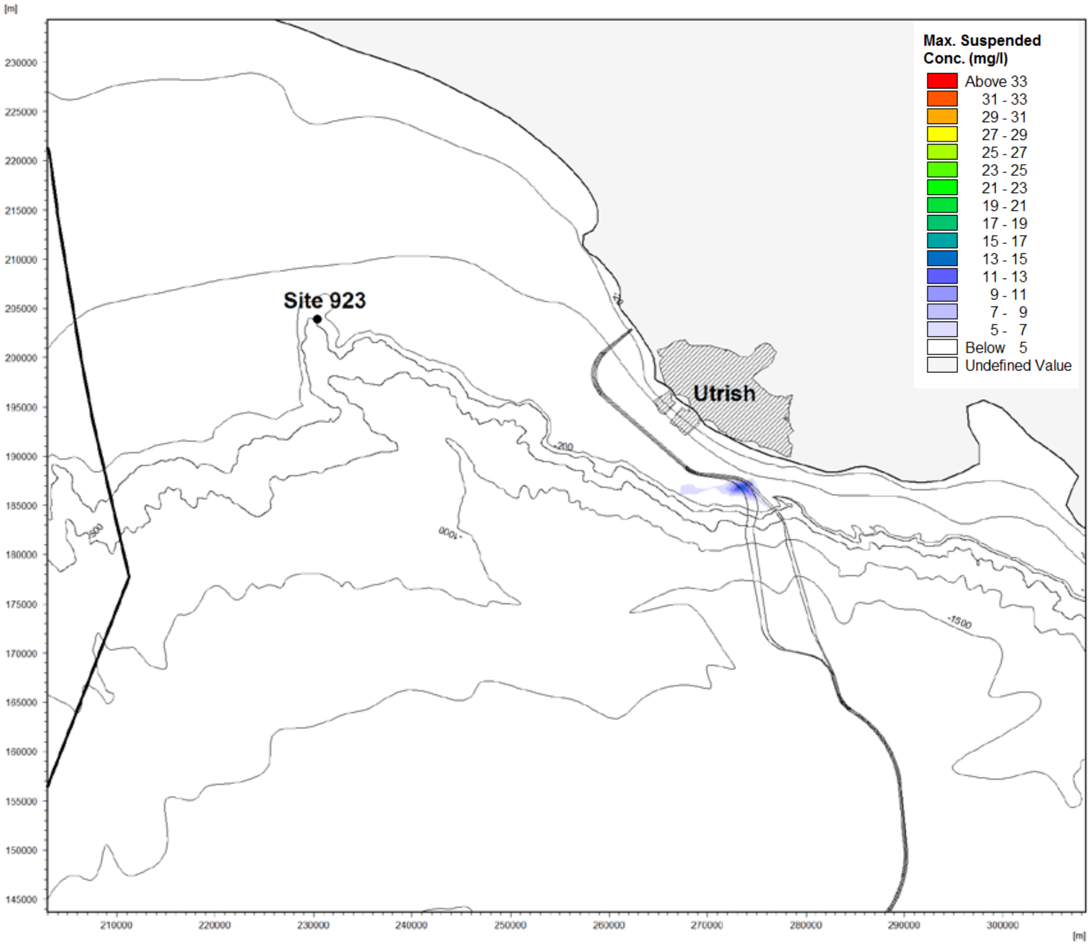


Figure 3-23 Maximum Bottom Plume Extent (Scenario 5)

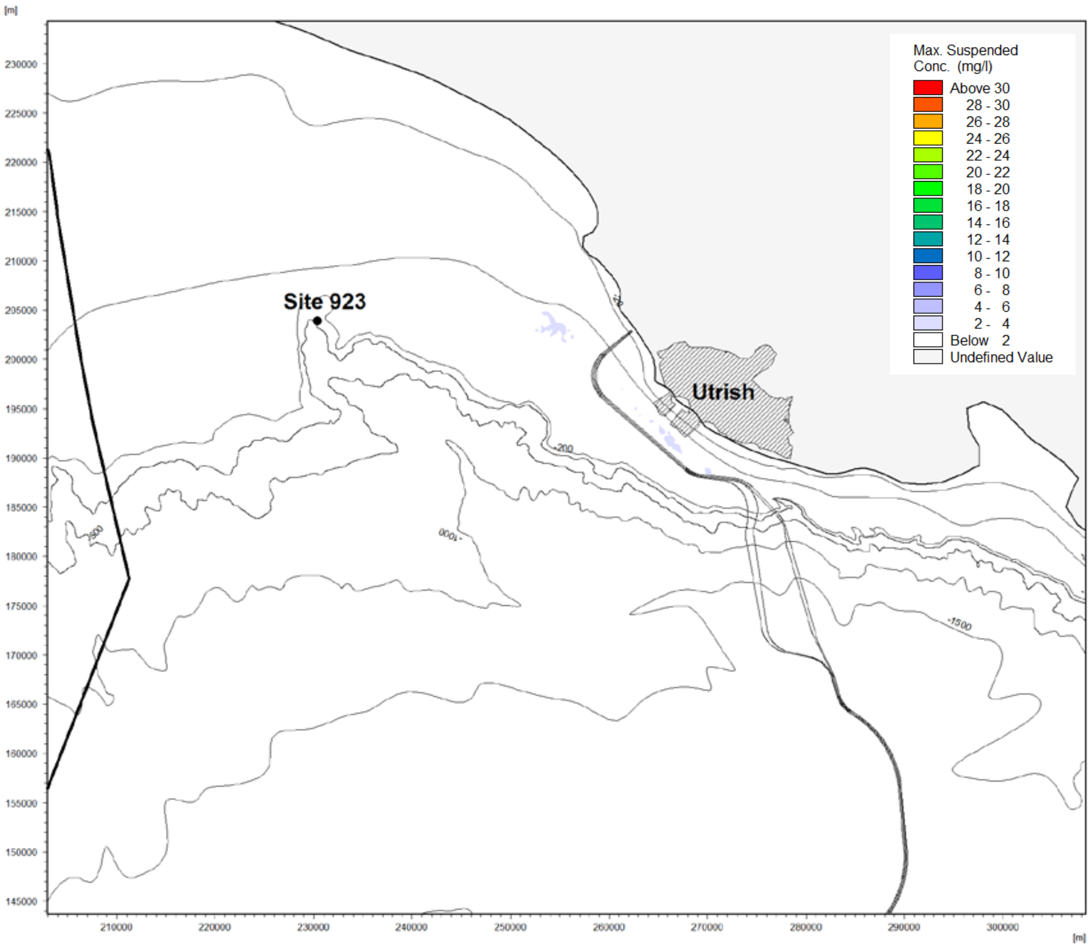


Figure 3-24 Maximum Surface Plume Extent (Scenario 6)

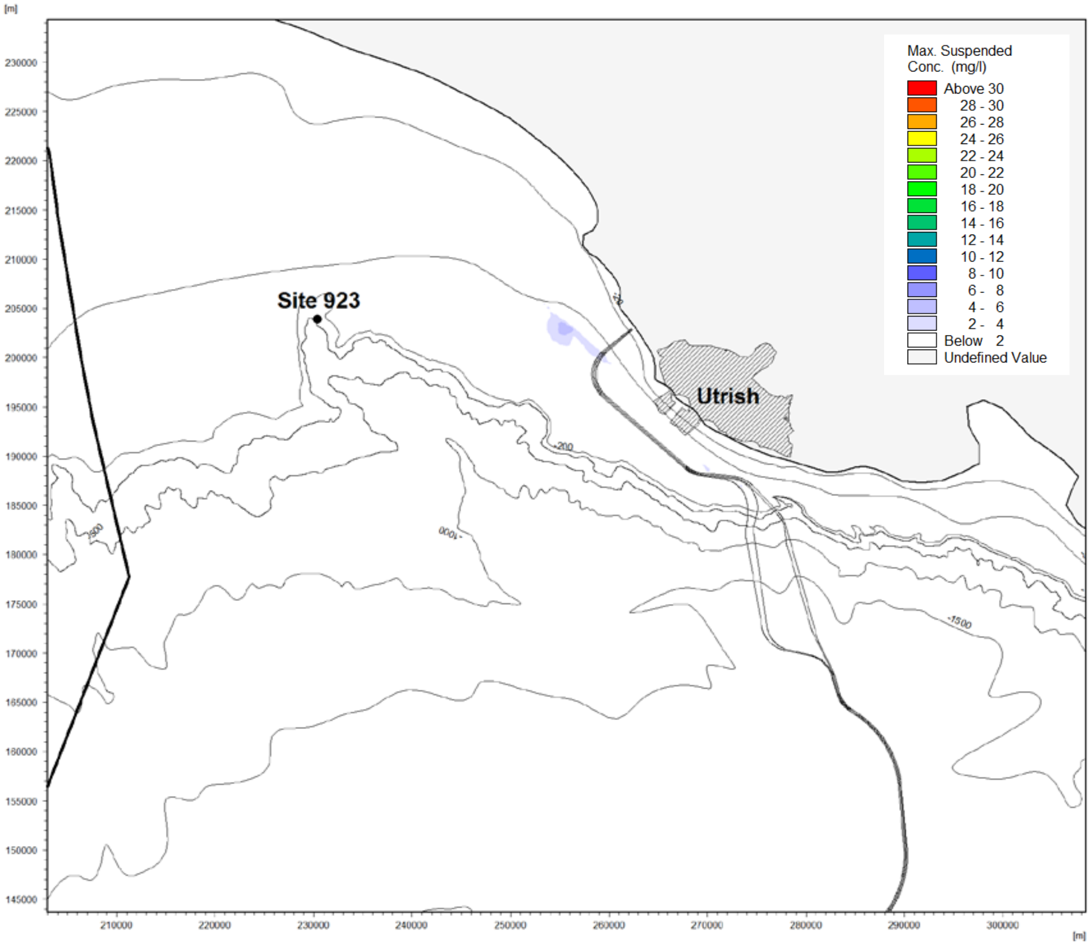


Figure 3-25 Maximum Depth-averaged Plume Extent (Scenario 6)

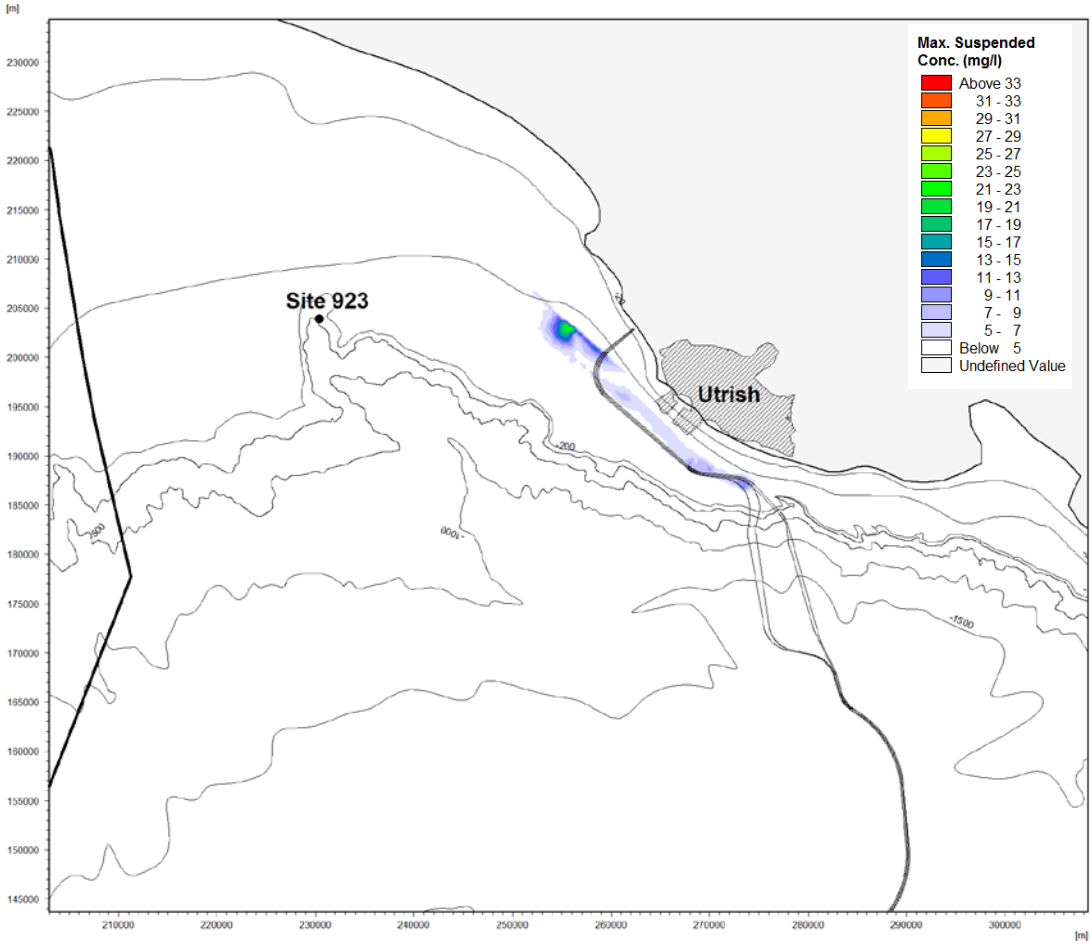


Figure 3-26 Maximum Bottom Plume Extent (Scenario 6)

Table 3-7 Distance and Area Affected by Plume for Surface Layer (post-lay)

Scenarios		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
5	distance (km)						1.2
	area (km^2)						1.4
6	distance (km)					19.0	30.0
	area (km^2)					16.7	80.9

Table 3-8 Distance and Area Affected by Plume for Depth-averaged Conditions (post-lay)

Scenarios		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
5	distance (km)					1.2	6.1
	area (km^2)					1.3	8.4
6	distance (km)				21.0	26.0	35.0
	area (km^2)				0.9	15.0	66.0

Table 3-9 Distance and Area Affected by Plume for Bottom Layer (post-lay)

Scenarios		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
5	distance (km)			1.1	4.0	18.0	21.0
	area (km^2)			1.6	17.5	102.2	652.5
6	distance (km)		23	28.0	30.0	36.0	43.0
	area (km^2)		1.7	10.5	49.2	164.8	278.2

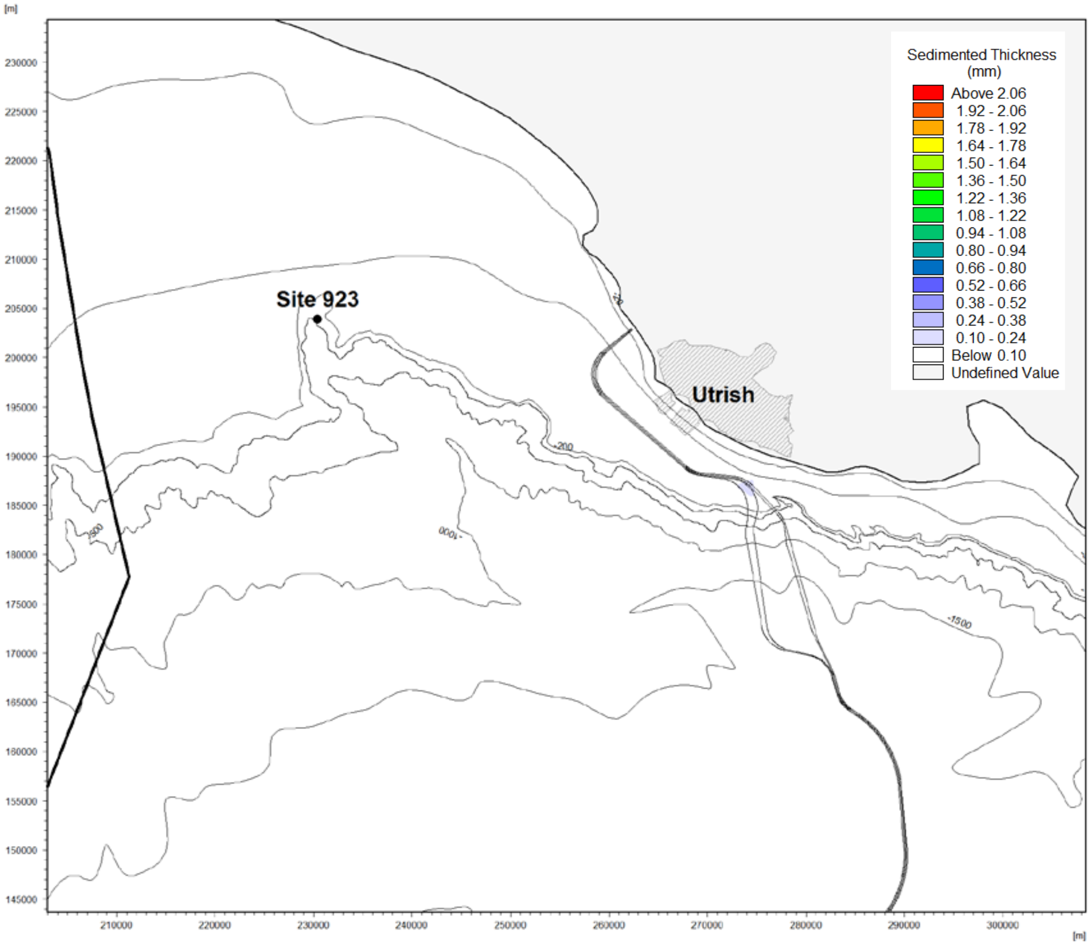


Figure 3-27 Maximum Sediment Thickness (Scenario 5)

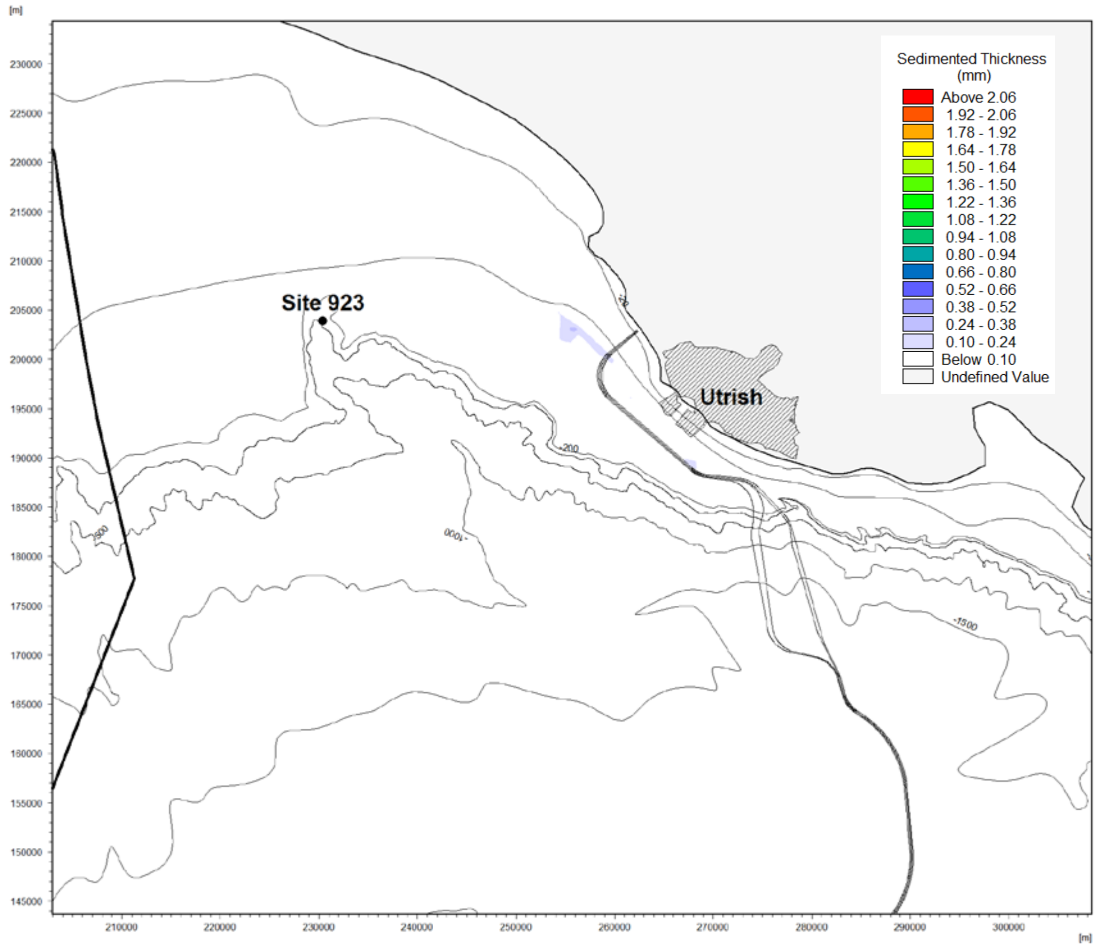


Figure 3-28 Maximum Sediment Thickness (Scenario 6)

3.2.4 Flocculation

Sensitivity of the predicted sediment plumes to the flocculation process was tested for Scenarios 1, 2 3 and 4 in which a large plume was predicted to occur without activating this process in the model. In the absence of field data, a settling velocity of 5.0e-4 m/s and critical shear stress for erosion of 0.10N/m^2 have been assumed based on Whitehouse et al. (1999).

Figure 3-29 and Figure 3-30 show the maximum extent of the depth-averaged plume for a threshold concentration of 2mg/l for Scenarios 1 and 2. The recorded maximum concentrations are 58mg/l (Scenario 1) and 120mg/l (Scenario 2). Table 3-10 summarises the maximum affected area and distance from the dredging or dumping site. The recorded maximum thickness of sediment accumulation on the bed is 56mm for Scenario 1 and 94mm for Scenario 2, as shown in Figures 3-31 and 3-32.

The modelled plume results of Scenarios 3&4 are illustrated in Figures 3-33 to 3-38. The recorded maximum concentrations are 273mg/l (Scenario 3) and 167mg/l (Scenario 4). Tables 3-11, 3-12 and 3-13 summarise the maximum affected area and distance from the dredging or dumping site. The recorded maximum thickness of sediment accumulation on the bed is 7.7mm for Scenario 3 and 3.8mm for Scenario 4, as shown in Figures 3-39 and 3-40.

The model results show that the plume is dispersed to a lesser degree and the formation of sediment flocs results in a reduced extent of the sediment plume and a higher deposition. The results presented with and without the flocculation process accounted for in the model provide an envelope for the likely impact in terms of the plume extent and concentration levels.

Further refinement of the predicted impacts would require an in-depth review of research in this subject area supported by field studies carried out during dredging and dumping activities.

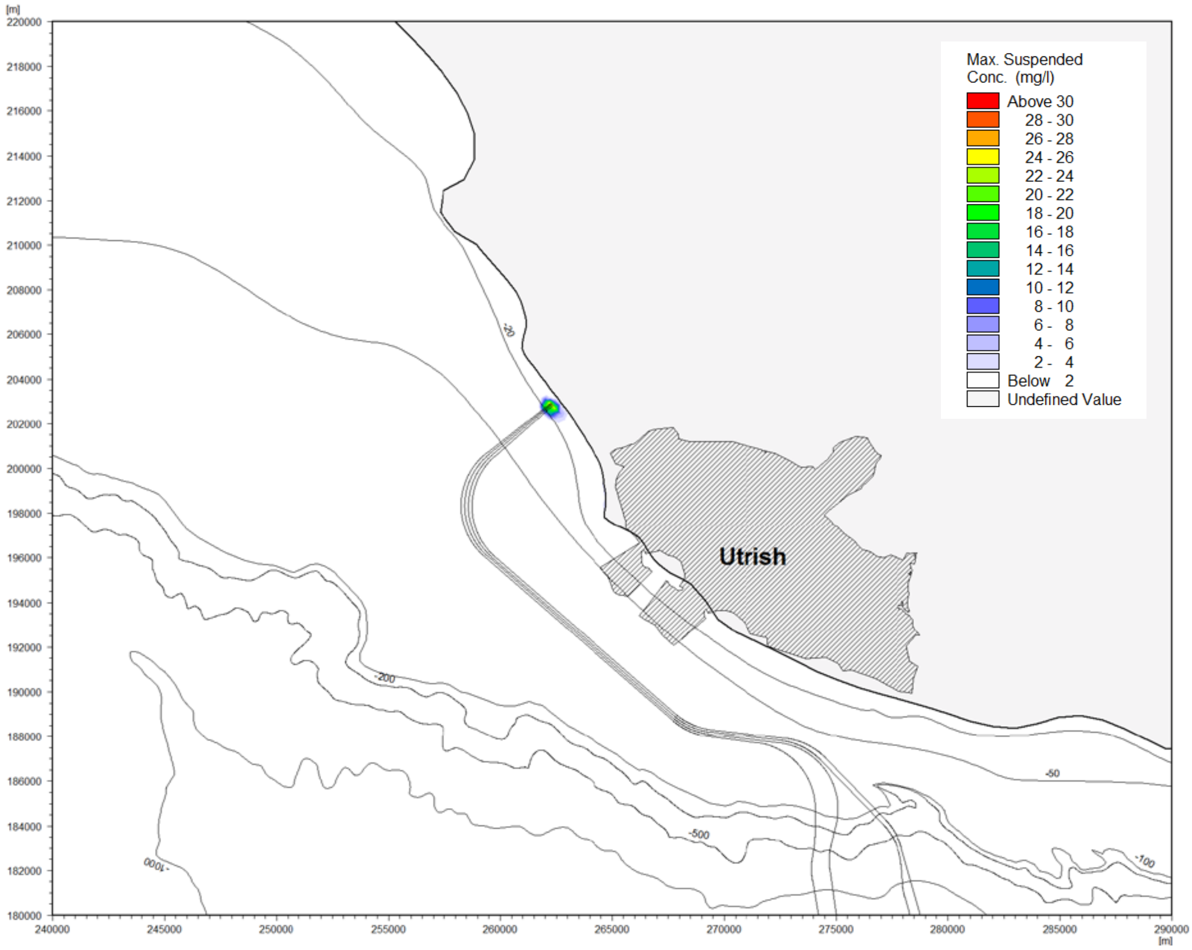


Figure 3-29 Maximum Plume Extent (Scenario 1)

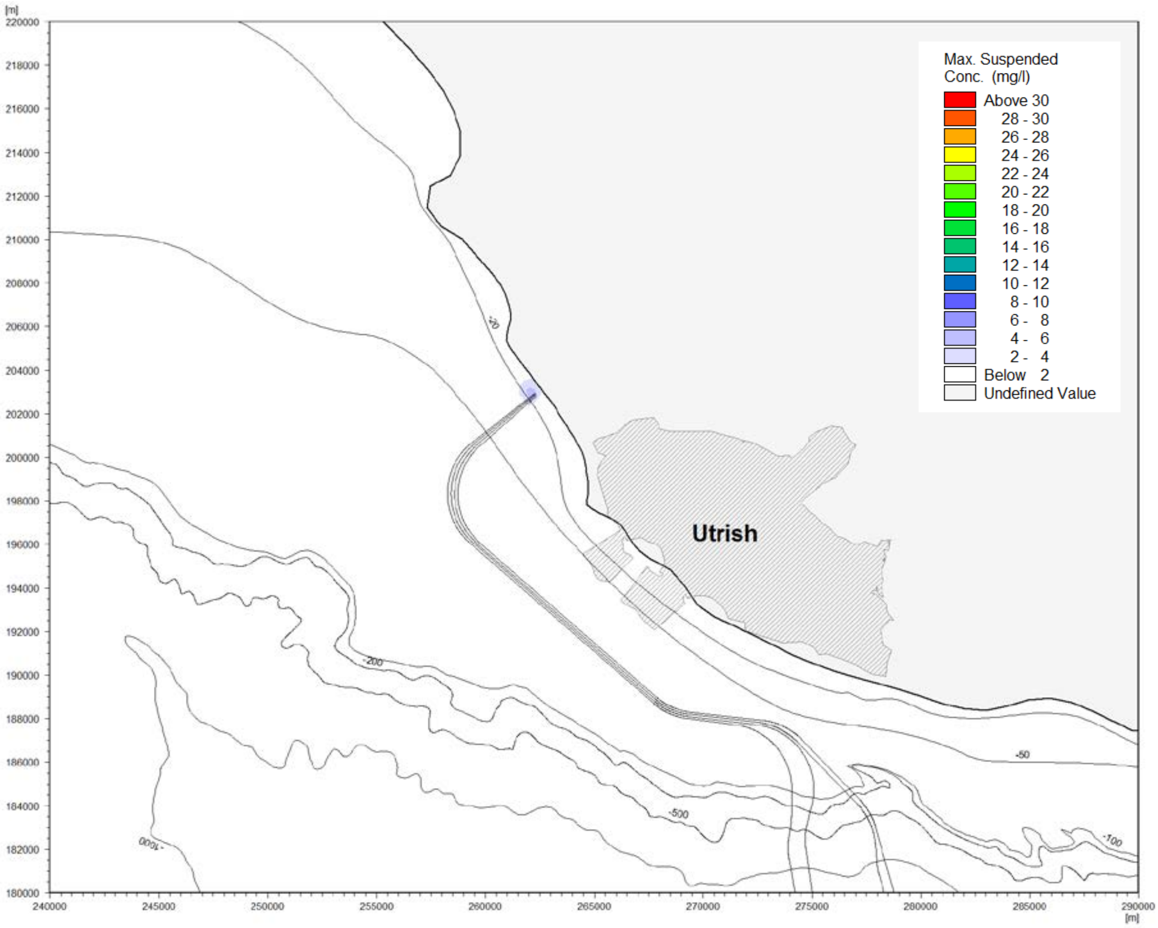


Figure 3-30 Maximum Plume Extent (Scenario 2)

Table 3.10 Distance and Area Affected by the Plume

Scenario		**≥ 50** (mg/l)	**≥ 20** (mg/l)	**≥ 10** (mg/l)	**≥ 5** (mg/l)	**≥ 2** (mg/l)	**≥ 1** (mg/l)
1	distance (km)		0.50	0.70	0.85	1.00	1.50
	area (km^2)		0.18	0.22	0.50	0.80	1.20
2	distance (km)	0.05	0.45	0.55	0.75	0.85	1.10
	area (km^2)	0.10	0.12	0.18	0.36	0.68	0.74

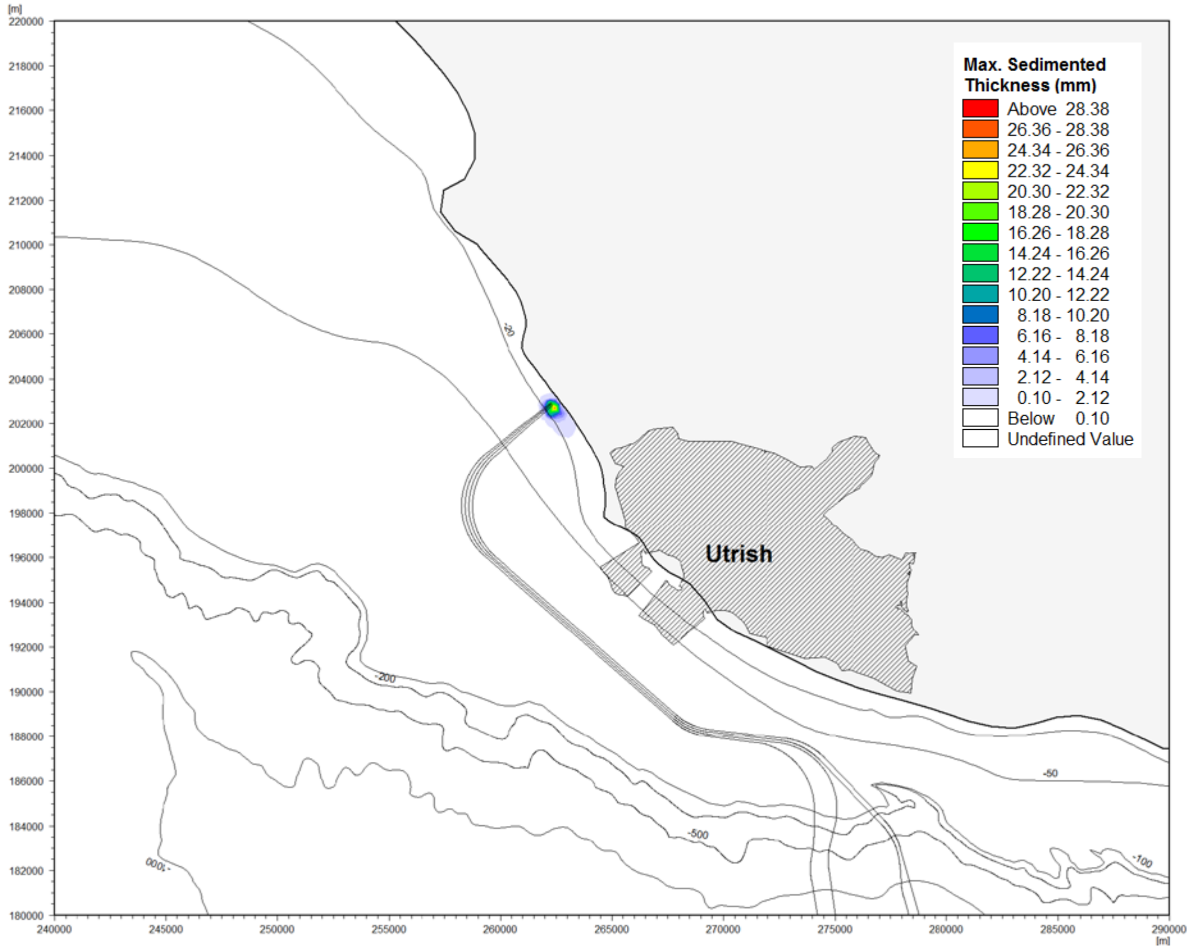


Figure 3-31 Maximum Sediment Thickness (Scenario 1)

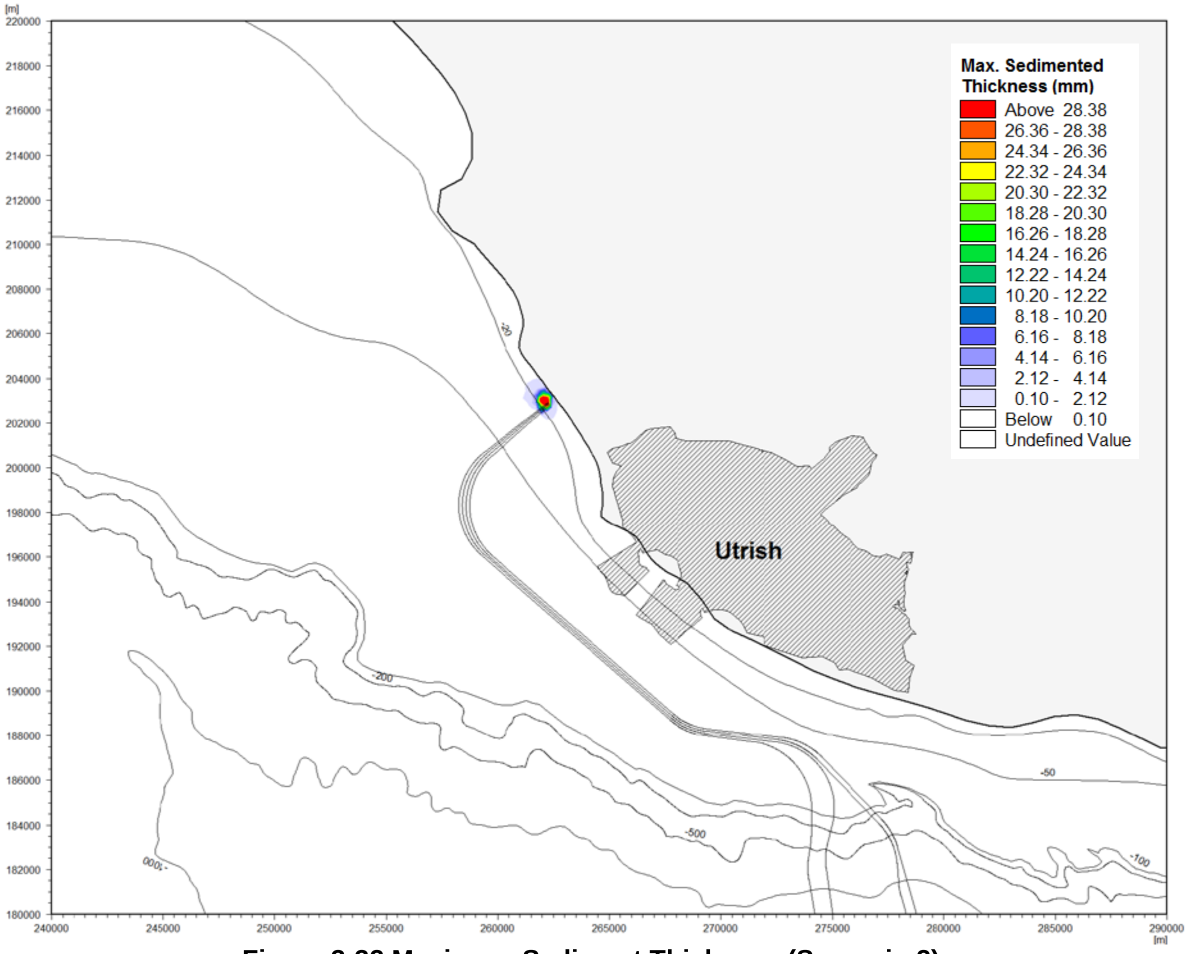


Figure 3-32 Maximum Sediment Thickness (Scenario 2)

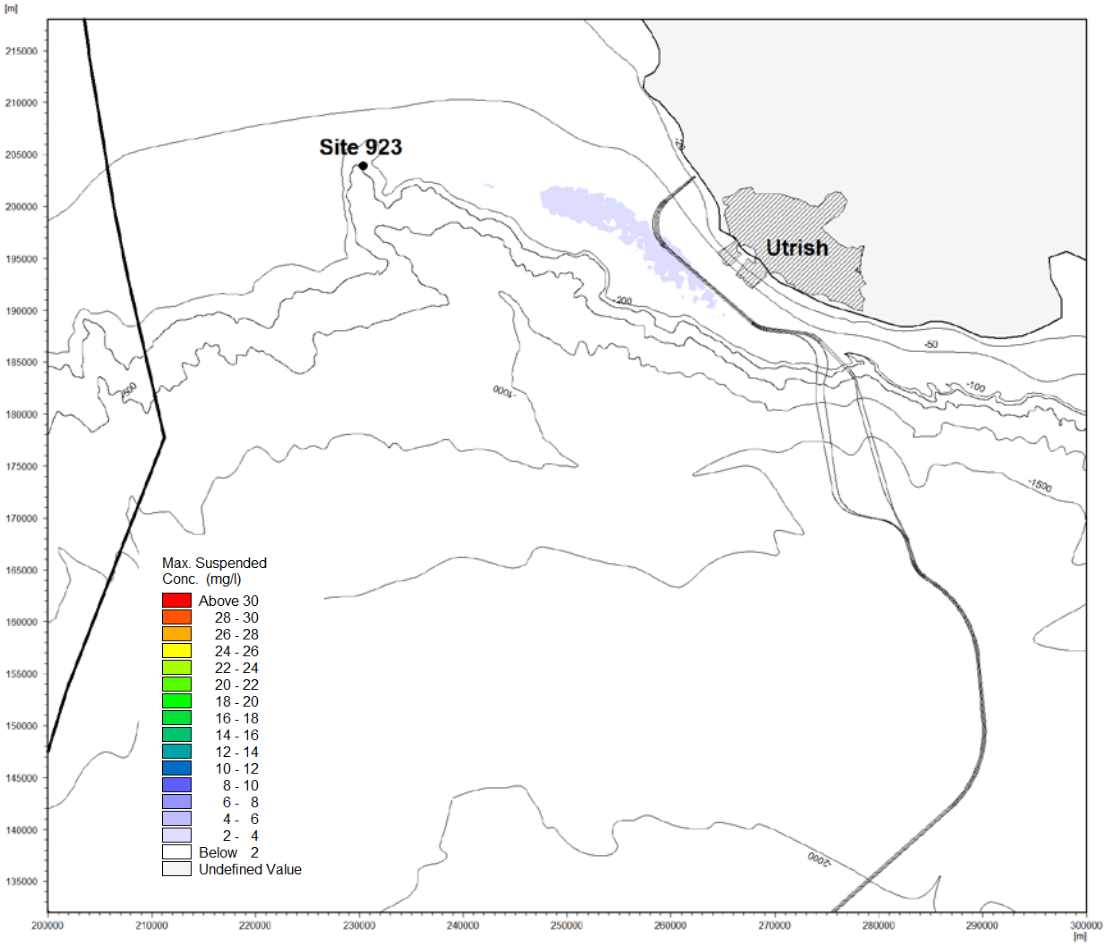


Figure 3-33 Maximum Surface Plume Extent (Scenario 3)

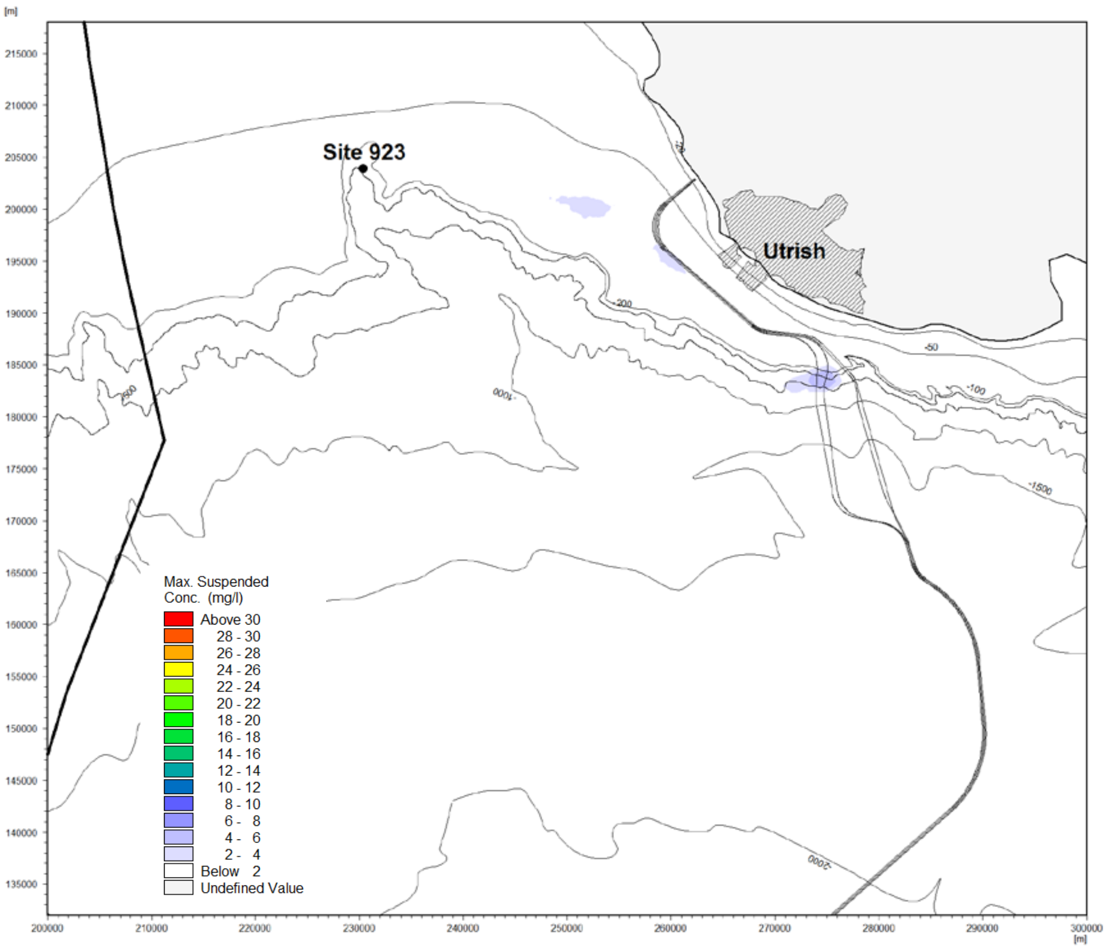


Figure 3-34 Maximum Depth-averaged Plume Extent (Scenario 3)

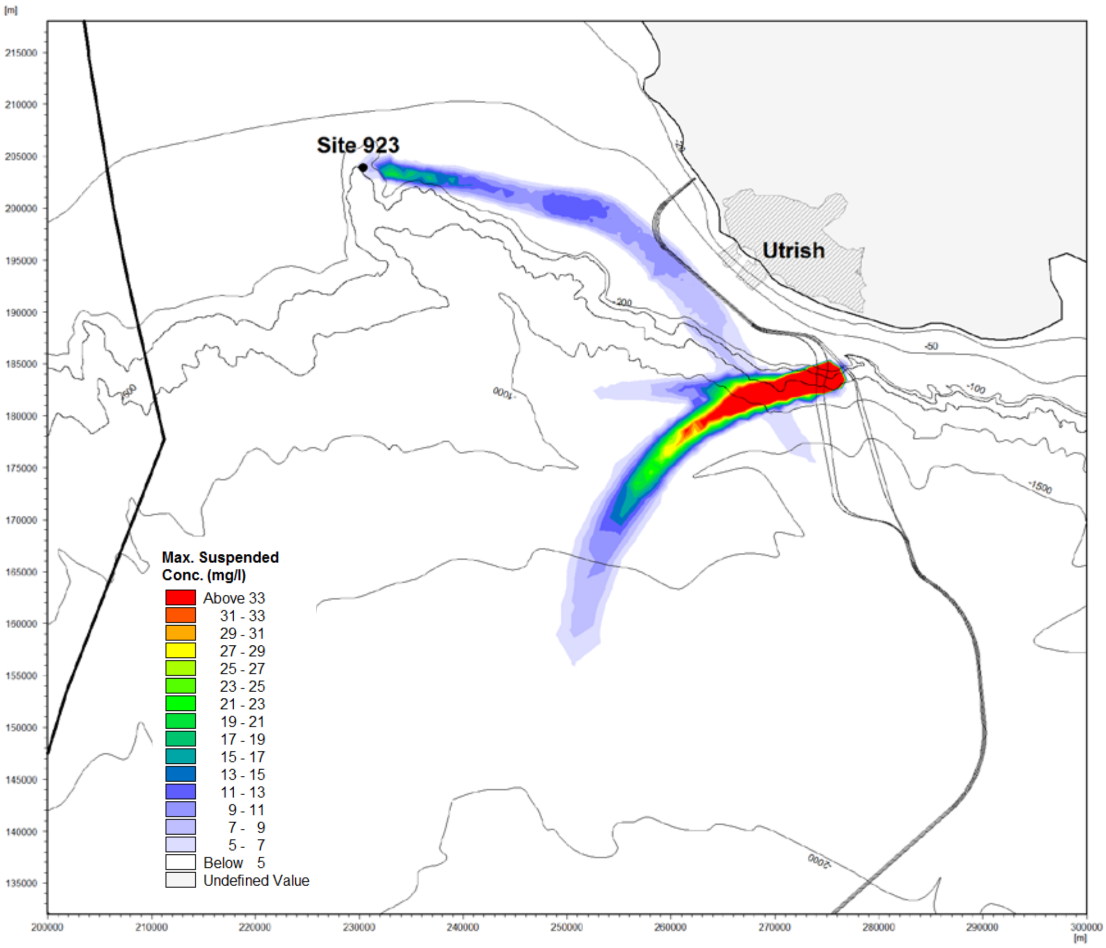


Figure 3-35 Maximum Bottom Plume Extent (Scenario 3)

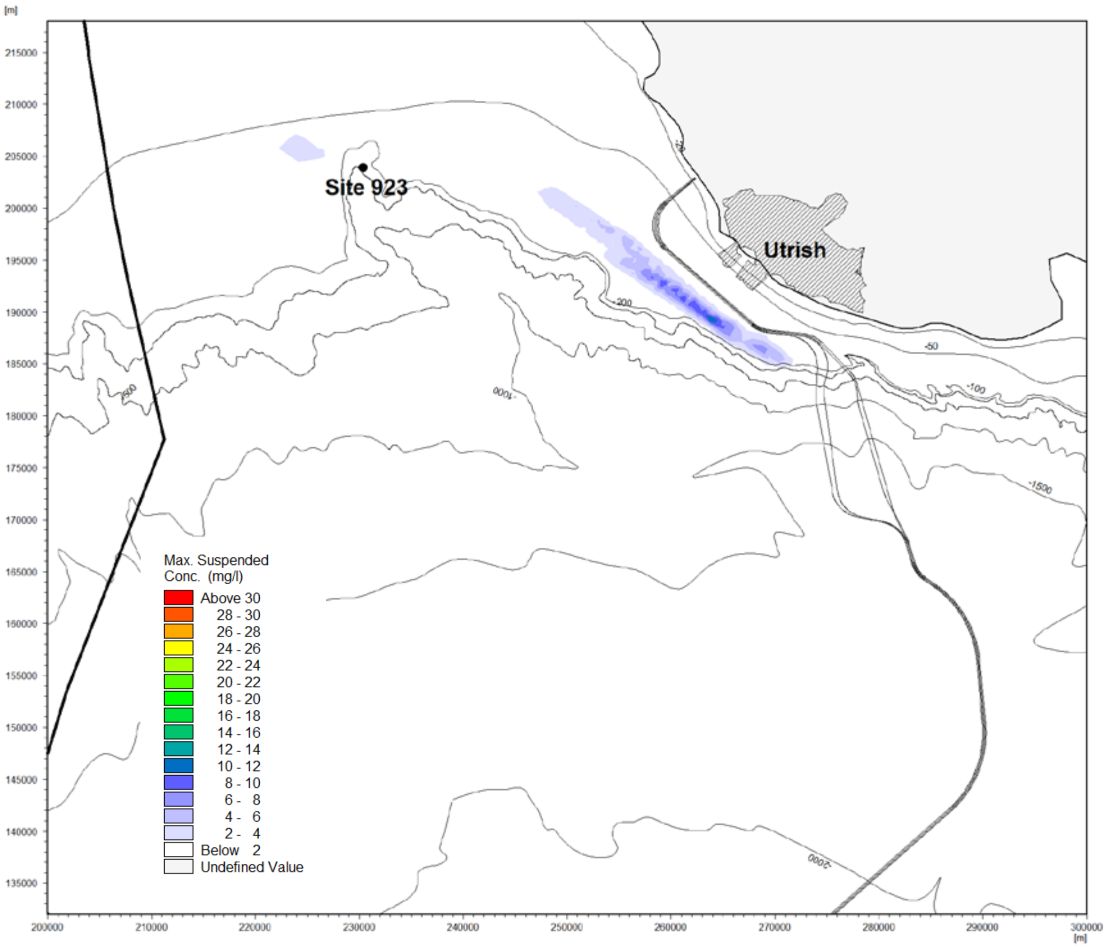


Figure 3-36 Maximum Surface Plume Extent (Scenario 4)

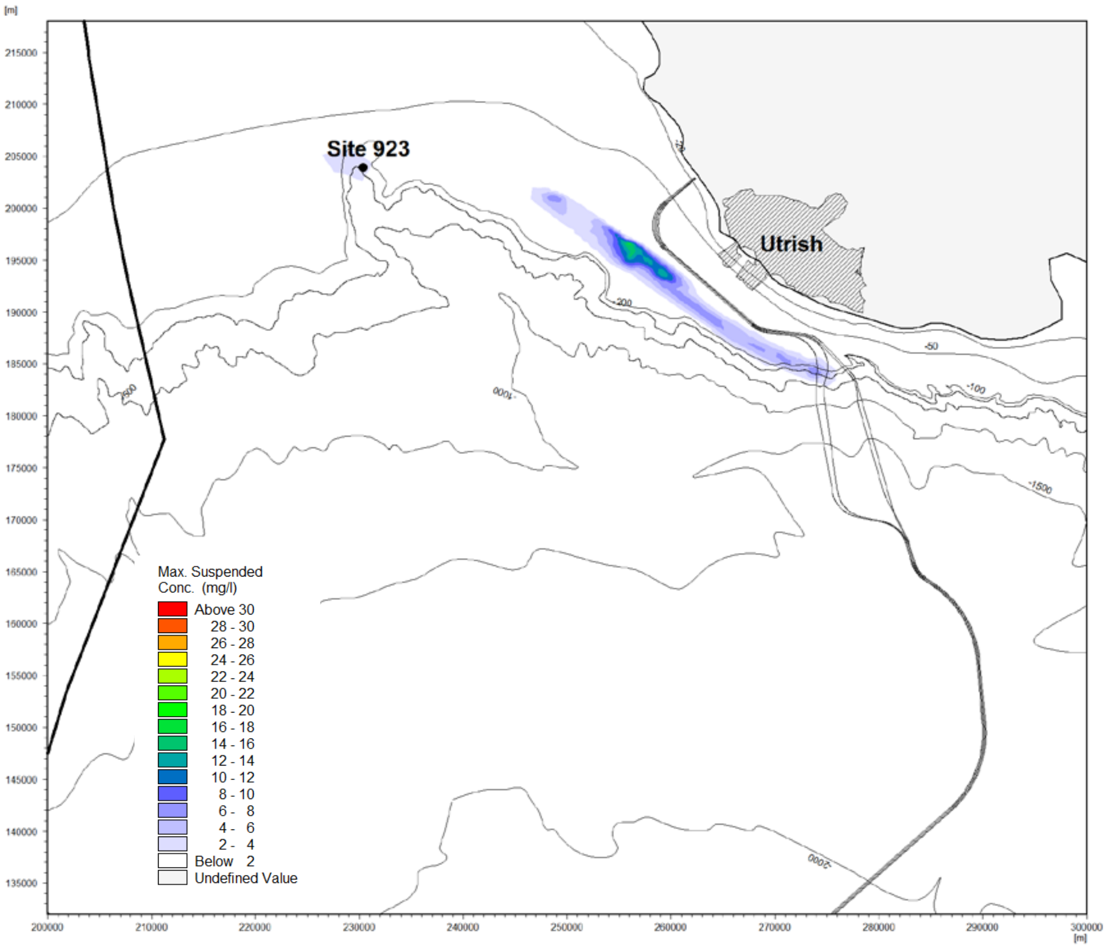


Figure 3-37 Maximum Depth-averaged Plume Extent (Scenario 4)

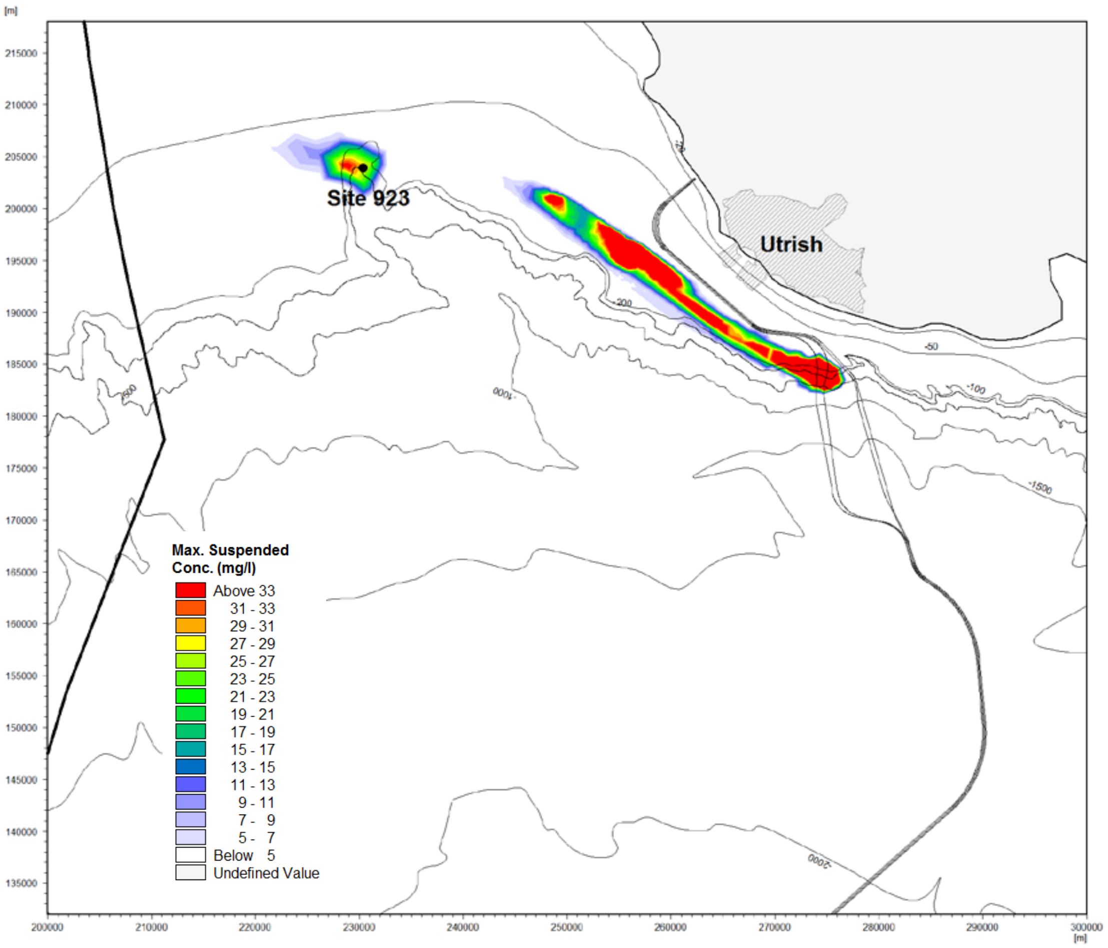


Figure 3-38 Maximum Bottom Plume Extent (Scenario 4)

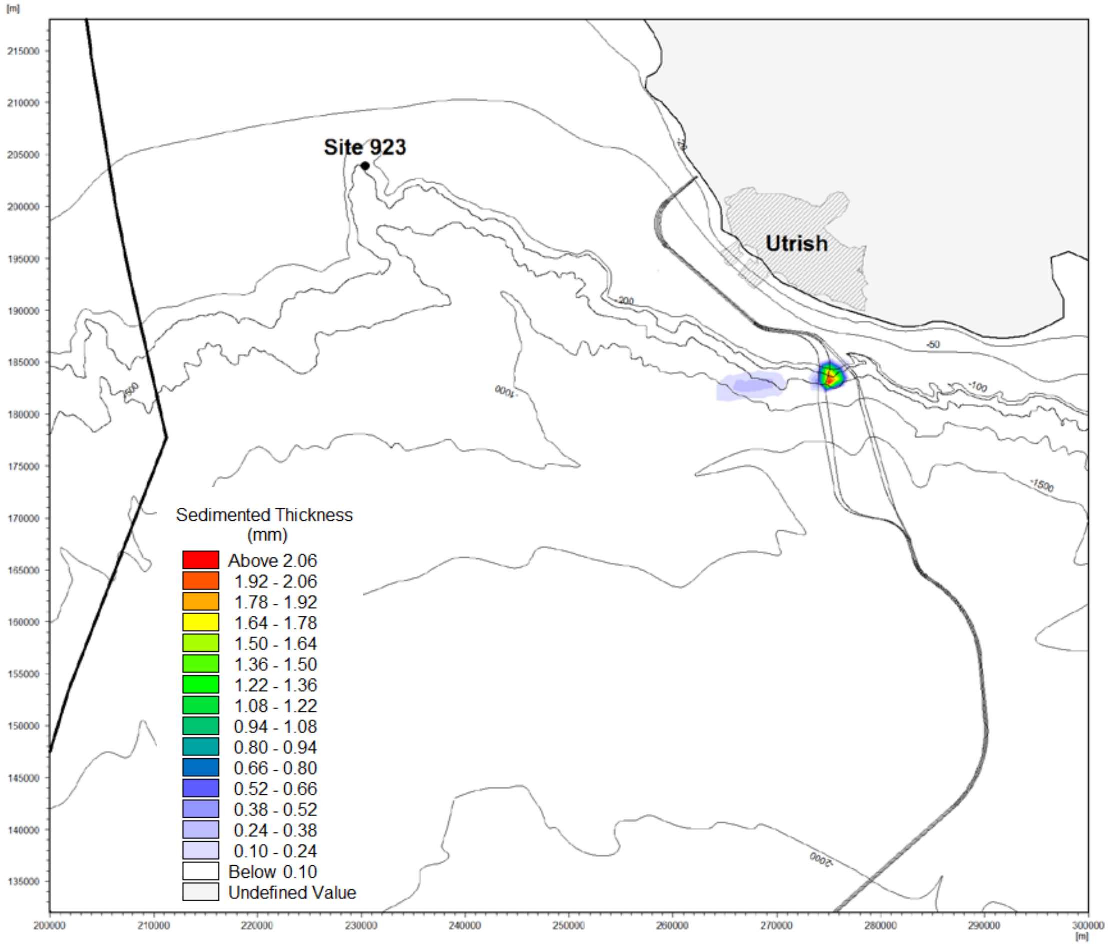


Figure 3-39 Maximum Sediment Thickness (Scenario 3)

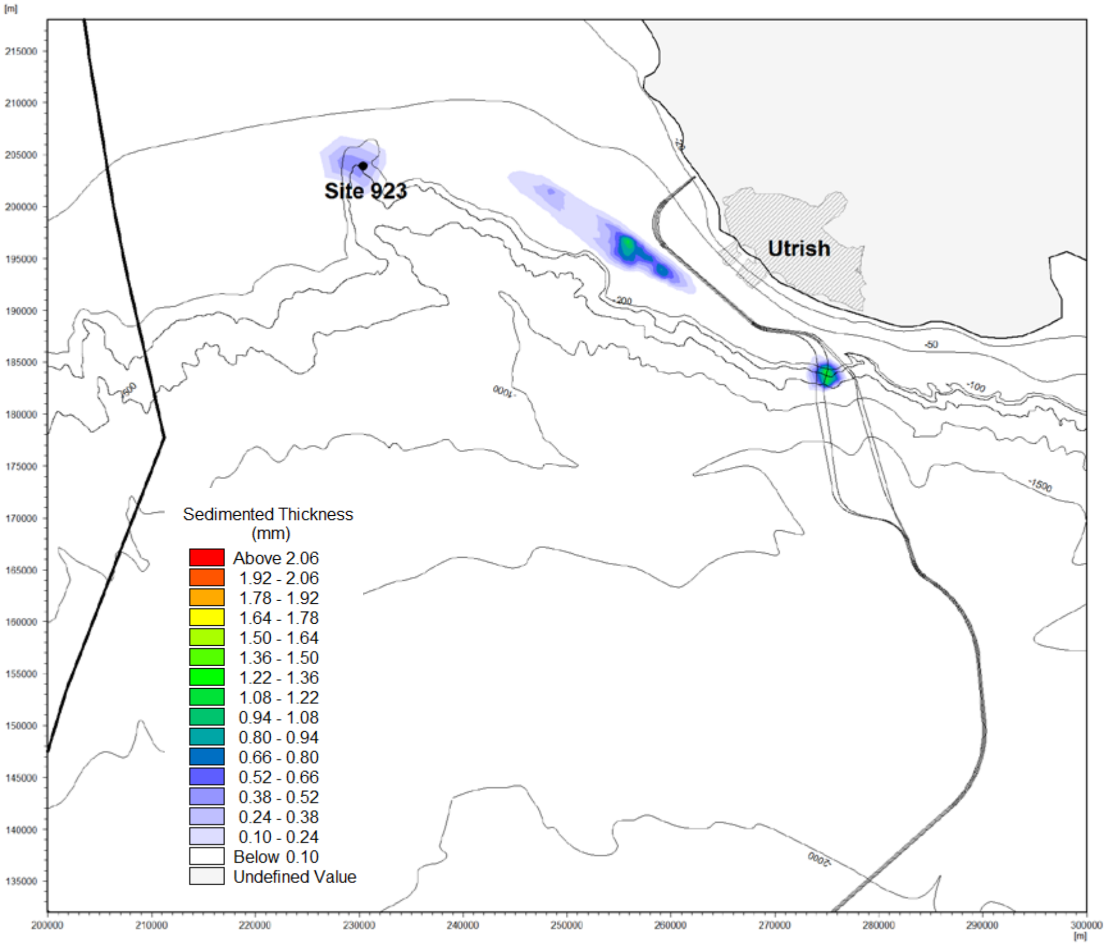


Figure 3-40 Maximum Sediment Thickness (Scenario 4)

Table 3-11 Distance and Area Affected by Plume at Surface Layer (pre-lay)

Scenarios		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
3	distance (km)					30.0	38.0
	area (km^2)					50.0	116.0
4	distance (km)			15.0	26.0	32.0	34.0
	area (km^2)			4.7	23.1	71.0	113.0

Table 3-12 Distance and Area Affected by Plume for Depth-averaged Conditions (pre-lay)

Scenarios		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
3	distance (km)				1.3	29.0	50.0
	area (km^2)				2.7	21.5	126.1
4	distance (km)			24.0	32.0	36.0	38.0
	area (km^2)			11.9	41.6	87.4	121.7

Table 3-13 Distance and Area Affected by Plume for Bottom Layer (pre-lay)

Scenario		≥ 50 (mg/l)	≥ 20 (mg/l)	≥ 10 (mg/l)	≥ 5 (mg/l)	≥ 2 (mg/l)	≥ 1 (mg/l)
3	distance (km)	7.0	22.0	30.0	59.0	95.0	102.0
	area (km^2)	12.3	49.9	156.1	351.3	1334	2800
4	distance (km)	27.0	33.0	35.5	37.0	41.5	45.0
	area (km^2)	22.8	67.3	91.1	130.5	193.0	238.0

4 CONCLUSIONS

The sediment plumes arising from the construction of the gas pipelines along the Russian coast have been assessed using the MIKE FM Particle Tracking model. This approach includes the influence of a range of hydrodynamic and meteorological conditions (wind and current speed and direction) typical for the site. A total of six modelling scenarios representing different tidal currents, dredging and disposal conditions have been investigated (Table 3-1). The model results were then used to define the spatial extent of the turbidity and sedimentation over the model domain.

Six threshold concentrations (1mg/l, 2mg/l, 5mg/l, 10mg/l, 20mg/l and 50mg/l) have been used to investigate the scale of impact. The model shows that the plume is barely visible at the surface. Close to the seabed, the plume is much larger in area and is subject to resuspension of sediment. The resuspended fine sediments will migrate and distribute over a large area. The presence of the plume will persist throughout the construction dredging activities, gradually dissipating following their completion.

Dredging at the microtunnel exit pits (Scenarios 1 and 2) results in a sediment plume after dredging works start. The sediment plume travels in the direction of the current along the Russian coastline. The impact is confined within a distance of 20 km from the dredging and disposal location where the maximum area of the plume (for a 2mg/l threshold) is approximately 40 km^2. The recorded maximum concentrations are 1300mg/l under clockwise current conditions and 5600mg/l under counter-clockwise current conditions.

For the pre-lay dredging/dumping on the Russian Slope (Scenario 3 and 4), the operations consider 16 journeys between the proposed dredging and disposal site. The results indicate that the affected distance and area are dependent on the current direction, position in the water column and the threshold of concentration, as summarised in Tables 3-2 to 3-9. The extent of the plume defined by a depth-averaged concentration of 2mg/l is less than 41km, whilst the area affected is up to 143km^2. The recorded maximum concentrations are 5.0 mg/l at the surface, 52mg/l near the bed but only 5.6mg/l when averaged through the water column.

For the post-lay trenching operation on the shelf (Scenario 5 and 6), the operation considers the material is pushed aside from the pipeline. The extent of the plume defined by a depth-averaged concentration of 2mg/l is less than 26km and the affected area is up to 15km^2. The recorded maximum concentrations are 3.5mg/l at the surface, 25.0mg/l near the bed and 6.2mg/l averaged through the water column.

The sensitivity of the results from the sediment plume modelling to the flocculation process has been investigated and the results show that the plume disperses to a lesser degree and a higher deposition is predicted by the model when this process is activated. The results presented, with and without flocculation effects accounted for, provide an envelope of the potential sediment plume extent, suspended concentration levels and depths of sediment accumulation on the seabed. Further refinement of the predicted impacts would require an in-depth review of research in this subject area supported by field studies carried out during dredging and dumping activities.

The findings presented in this report are limited by the reliability of the information applied within the study. The results of the particle-tracking model have not been validated against field data. Parameters adopted in the modelling are based on the recommended values supported by published formulations. A further limitation concerns the hydrodynamic conditions which are restricted to two 15-day periods in 2008 which were chosen to represent the typical range in conditions. The limited duration of these datasets may not fully capture the variability in environmental conditions. The approach adopted is however expected to provide an adequate representation of potential environmental impacts since construction activities are likely to be suspended during more extreme conditions.

5 REFERENCES

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