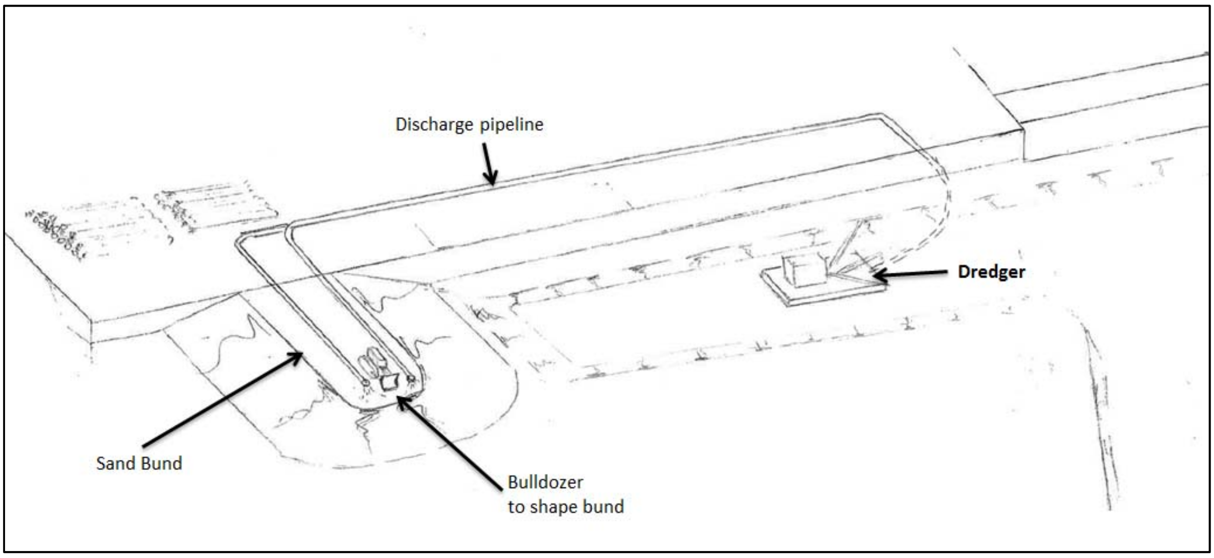

Nigg Energy Park

Additional Sediment Plume Modelling

Main Report and Appendices

Global Energy Nigg Limited

August 2013
Final Report
PB1107

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Appendix A LITPROF Modelling of Erosion from the Construction Berm

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Appendix C Scenario 3 Modelling Results

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1 BACKGROUND

Royal HaskoningDHV was appointed by Global Energy Nigg Ltd. to undertake sedimentation and wave modelling associated with the proposed South Quay Development at Nigg Energy Park, Cromarty Firth. This modelling was completed in May 2013 (Royal HaskoningDHV, 2013) and informed both the Environmental Statement and the maritime engineering concept design.

The proposed development involves the construction of a new 'L-shaped' quay extending seaward of the existing South Quay, together with dredging of a berthing pocket and adjacent seabed areas (referred to as Option 3C). Dredged material will be re-used as construction fill within the quay development, with the residual quantities disposed at a licensed site within the mouth of the Cromarty Firth, named The Sutors spoil ground.

The original concept design intention was for the new L-shaped quay to be constructed by first installing sheet piles using an installation vessel or jack-up barge and then back-filling the void in between the piles with dredged sand (Figure 1). During this operation, the infill material would be contained between the sheet piles and thus not exposed to marine action.

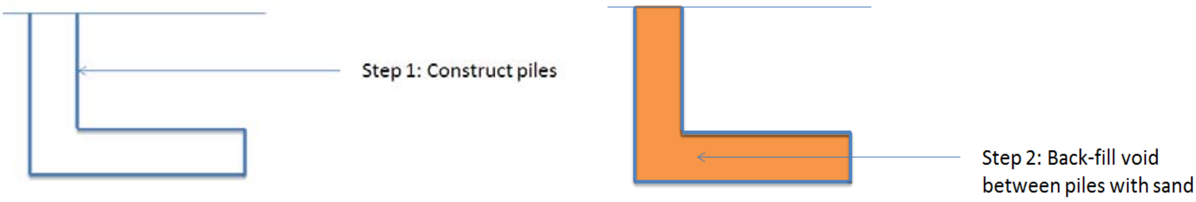


Figure 1 - Original construction method

During the tender process, an alternative construction method was identified which could, potentially, provide significant cost savings. This involves using the dredged material (predominantly sand) to create a berm along the alignment of the new L-shaped quay, from which land-based construction plant could install the piles through the side slopes and into the sea bed.

The berm and steel sheet piling would be constructed in stages, but always with an advanced head of material that is unconstrained by piles and therefore exposed to marine action (Figure 2). At the end of the quay construction, when all of the berm's length is contained within the sheet piles, there would be a final dredge to remove the side-slopes of the berm and achieve the desired berthing pocket depths. This material would be disposed at The Sutors spoil ground.

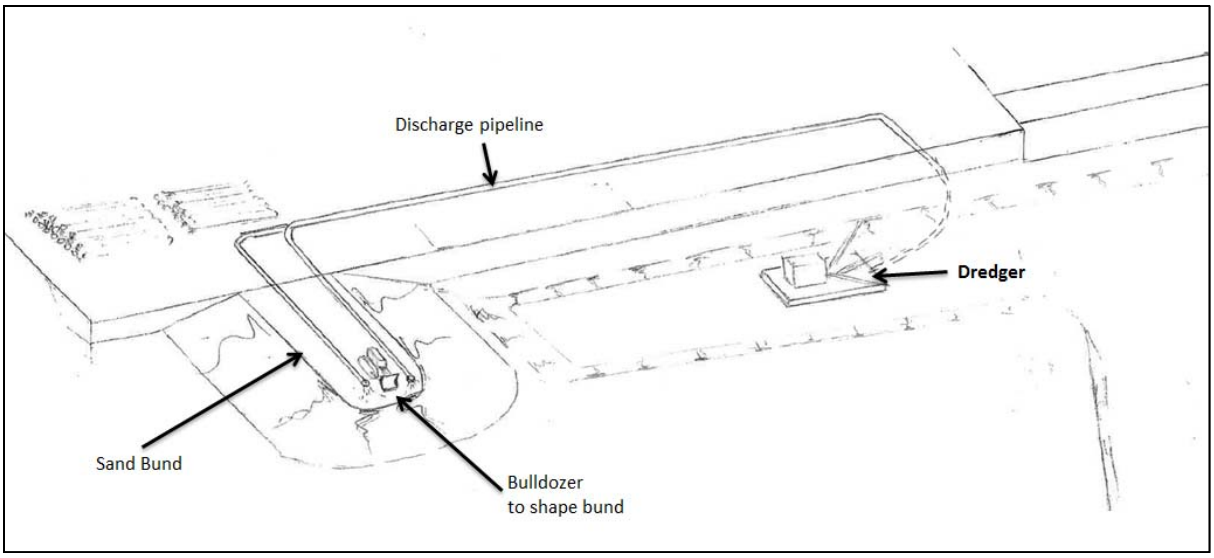


Figure 2 - Alternative construction method

The changes in suspended sediment concentrations and bed levels within the vicinity of the works and across a wider area of the Cromarty Firth and Inner Moray Firth, which may arise from the alternative construction method, need to be assessed to inform the further environmental assessments associated with the proposed alternative approach.

2 ASSESSMENT APPROACH

Based upon the proposed alternative construction method, there are five elements of activity that have been investigated in the assessment of a worst case scenario for this alternative approach. These are as follows:

- **Scenario 1:** Spillage losses from initial sea bed dredging activities.

- **Scenario 2:** Spillage losses during discharge of dredged material for construction of the berm.

- **Scenario 3:** Erosion of sediments from exposed sections of the berm during the sheet pile installation construction programme under 'typical' wave conditions (defined as 1 in 1 month wave events).

- **Scenario 4:** Erosion of sediments from exposed sections of the berm during the sheet pile installation construction programme under 'storm' wave conditions (defined as 1 in 1 year wave events).

- **Scenario 5:** Spillage losses from final sea bed dredging activities and disposal of remaining dredged material at The Sutors spoil ground.

The MIKE21-HD (hydrodynamic) numerical model and the MIKE21-MT (sediment plume) numerical model used in the previous modelling studies (Royal HaskoningDHV, 2013) to inform the Environmental Statement about potential effects of the original concept design intention remain suitable for use as the basis of these additional modelling assessments. These models were set up to simulate physical processes over an 18-day period to ensure coverage of a full neap-spring tidal cycle.

2.1 Scenario 1 Assessment

The original Environmental Statement previously assessed the effects of spillage losses from dredging activities, thereby covering Scenario 1. Scenario 5 was also covered by the previous assessments. This further assessment of effects therefore focuses on each of Scenarios 2 – 4, which represent the additional potential effects caused by the proposed alternative construction method.

2.2 Scenario 2 Assessment

As dredged material is pumped from the quay to form a berm, some of the sediments will remain deposited on the bed, but some will become 'spilled' into the water column and form a plume. To assess the effects of these activities, the following assumptions have been used in the sediment plume and sediment deposition modelling that was undertaken using the MIKE21-MT numerical model:

- All sediment has been released into the model domain at the 'worst case' release point, which is at the most south-westerly corner of the new L-shaped quay where the tidal currents and wave conditions are greatest (i.e. there is greatest potential for plume formation).

- The sediment characteristics have been defined according to the borehole information that is available from areas of proposed dredging for the fill material. The dredged sediment comprises the following proportions (as used in the previous modelling studies and reported in the ES):
    - Gravels 3%
    - Coarse sands 34%
    - Medium sands 42%
    - Fine sands 20%
    - Silts and clays 1%

- The release of sediments into the water column has been assumed at a rate of 1,000m^3/hour for an uninterrupted period of 5 days around the timing of the peak of the spring tides (i.e. in total 120,000m^3 of sediment is released into the model).

- The model simulates which particles are sufficiently large to reside on the bed and which particles will become entrained as a sediment plume based on the bed shear stresses created by tidal current action.

2.3 Scenarios 3 and 4 Assessment

In order to determine the effect on turbidity and bed levels due to sediments becoming eroded from the exposed sections of the berm, an estimate was first needed of the erosion losses under both 'typical' wave events and 'storm' wave events. This was provided using the numerical model LITPROF, a cross-shore profile model, and the resulting sediment volumes arising from the erosion processes were then fed into the MIKE21-MT plume model, where tidal currents are incorporated, to determine the formation and fate of plumes following the wave-induced erosion episodes.

Further details of the LITPROF modelling are provided in **Appendix A**, but in summary the 'shore' was represented by a single cross section through the seaward face of the berm, taken at its position most exposed to wave action, namely the south-westerly corner of the L-shaped alignment. The characteristics of the sediments comprising the berm were defined according to the borehole information that is available from areas of proposed dredging for the fill material. The dredged sediment compositions were as previously stated for Scenario 2 (and hence remain as used in the previous modelling studies and reported in the ES).

Wave conditions corresponding to 'typical' and 'storm' events were then applied to the seaward face of the berm for a duration of 12.5 hours; this being both a suitable timescale for a wave event and the duration over which one full tidal cycle occurs. The wave conditions were applied to the seaward face of the profile under the influence of a tidally-varying water level.

A 'typical' wave condition was defined as a 1 in 1 month return period wave height, while a 'storm' wave condition was taken as a 1 in 1 year return period wave height. For each return period event, consideration was given both to waves entering the Cromarty Firth through the mouth from the North Sea and to local wind-generated waves from the prevailing south-westerly wind direction.

The results indicate that under ‘typical’ conditions the berm would be relatively stable, with only minor deformations in its morphological form around the low and high water marks. Changes in the berm would be greater under a ‘storm’ event, but again the broad form of the berm would remain stable. This is largely a function of two parameters: (i) the sediment characteristics of the dredged material being relatively coarse (with 99% of the sediments being sands or gravels); and (ii) the side-slopes of the berm being relatively shallow, at a gradient of 1:6.

Due to this finding, further sensitivity tests were performed with a wider spread of sediment gradings to cover the possibility that a greater proportion of finer material than presently envisaged actually occurs in the dredged material. This demonstrated that if a greater than envisaged proportion of fine sands, silts and clays was in the sediment distribution then the berm would be subject to greater erosion volumes, but would nonetheless still remain broadly stable in form under the wave conditions considered.

As a worst case scenario, it was assumed that the erosion would occur at the southern end of the north-south aligned section of the L-shaped quay. At this location, the eastern side of the berm would be vulnerable to waves from the North Sea and the western side of the berm would be vulnerable to local wind-generated waves from the south-west. As a worst case scenario, the wave-generated erosion values from both wave directions were combined to ensure a conservative approach (in reality it is likely that erosion during a single storm event would occur from one side of the berm only).

It was further assumed that all material eroded from the berm by wave action could potentially become entrained by tidal currents and that the greatest length of exposed berm at any one time before sheet piling was installed would be 100m on each side of the berm. Based on the worst case ‘upper bound’ of the sediment grading sensitivity assessments, this resulted in the following volumes being inserted into the MIKE21-MT sediment plume numerical model:

- Scenario 3 – Under a ‘typical’ wave event, 1,220m^3 of sediment is released over a period of 12.5 hours.

- Scenario 4 – Under a ‘storm’ wave event, 1,840m^3 of sediment is released over a period of 12.5 hours.

2.4 Scenario 5 Assessment

The original Environmental Statement previously assessed the effects of spillage losses from dredging activities and the effects associated with the disposal of sediments at The Sutors spoil ground, thereby already covering Scenario 5. Scenario 1 was also covered by the previous assessments. This further assessment of effects therefore focuses on each of Scenarios 2 – 4, which represent the additional potential effects caused by the proposed alternative construction method.

3 MODELLING RESULTS

Appendices B, C and D present the results from the plume modelling for Scenarios 2, 3 and 4 respectively. Results are shown as spatial plots of elevated suspended sediment concentrations (in kg/m^3) above notional background levels. These values can be translated to units of mg/l by multiplying by a factor of 1×10^3.

3.1 Scenario 1 Modelling Results

The effects of spillage losses from the initial sea bed dredging activities were addressed within the previous sediment plume and sediment deposition modelling studies. These were reported in Section 7 of the previous modelling report (Royal HaskoningDHV, 2013).

3.2 Scenario 2 Modelling Results

Results in **Appendix B** are plotted at hourly intervals for the first 24 hours of the simulation, followed by daily intervals thereafter until day 6, when the elevated suspended sediment concentrations return to notional background values.

It can be seen that a sediment plume is created immediately upon commencement of sediment discharging activities from the quay to form the berm. The plume remains relatively localised to the point of discharge, with a high suspended sediment concentration at its centre (200-600mg/l), but rapidly drops to lower concentrations (<135mg/l) with distance from the point of discharge. The shape of the plume changes through the tidal cycle, becoming more asymmetrical around times of peak flood and peak ebb currents, and more symmetrical around times of slack water. The suspended sediment concentrations within the plume remain relatively constant over time for the first 5 days of the simulation. This is due to the continuous discharge of sediment into the model during this period. The suspended sediment concentrations then reduce back to notional background values within 1 day of cessation of discharging operations.

The maximum elevated suspended sediment concentrations observed at any point during the model simulation are shown in Figure 3. This indicates that the maximum potential effects arising from the discharging activities are expected to be localised to the vicinity of the development area. The bed thickness changes at the end of the 18-day model simulation period are shown in Figure 4. This indicates that due to the relatively coarse nature of the vast majority of the dredged sediment used to form the berm, much will reside on the bed after discharge from the quay.

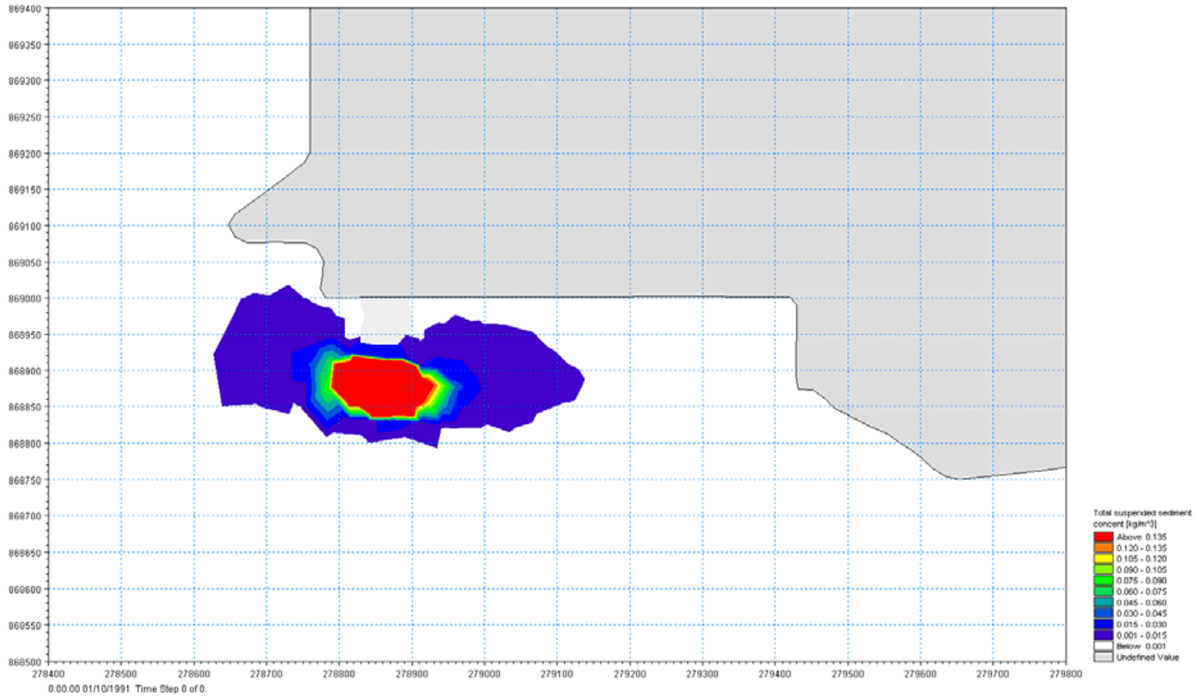


Figure 3 - Maximum suspended sediment concentrations during release

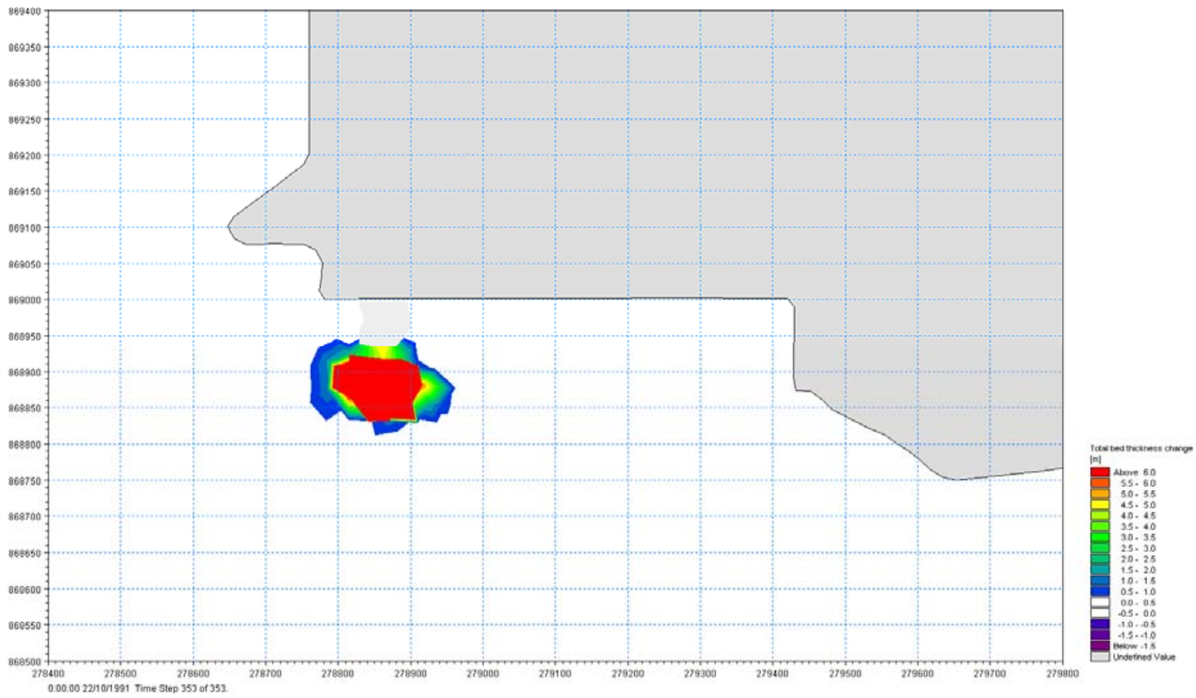


Figure 4 - Bed thickness change at end of model run

Figure 5 shows the variations in suspended sediment concentrations over time at the discharge site and at five other key locations across the wider area of interest within Cromarty Firth. This shows that at the discharge site, suspended sediment concentrations reach peak values of around 600mg/l, reducing to minimum values of around 200 – 300mg/l (depending on timing within the tidal cycle) during the five days of continuous discharging, but values drop to notional background levels almost immediately upon cessation of activities. Elevated suspended sediment concentrations are recorded at none of the other five sites selected from around the wider Cromarty Firth. These results demonstrate that the discharging activities to form a construction berm will have temporary effects only, although the elevations in suspended sediment concentrations will be high (up to 600mg/l) at points very localised to the discharging activities.

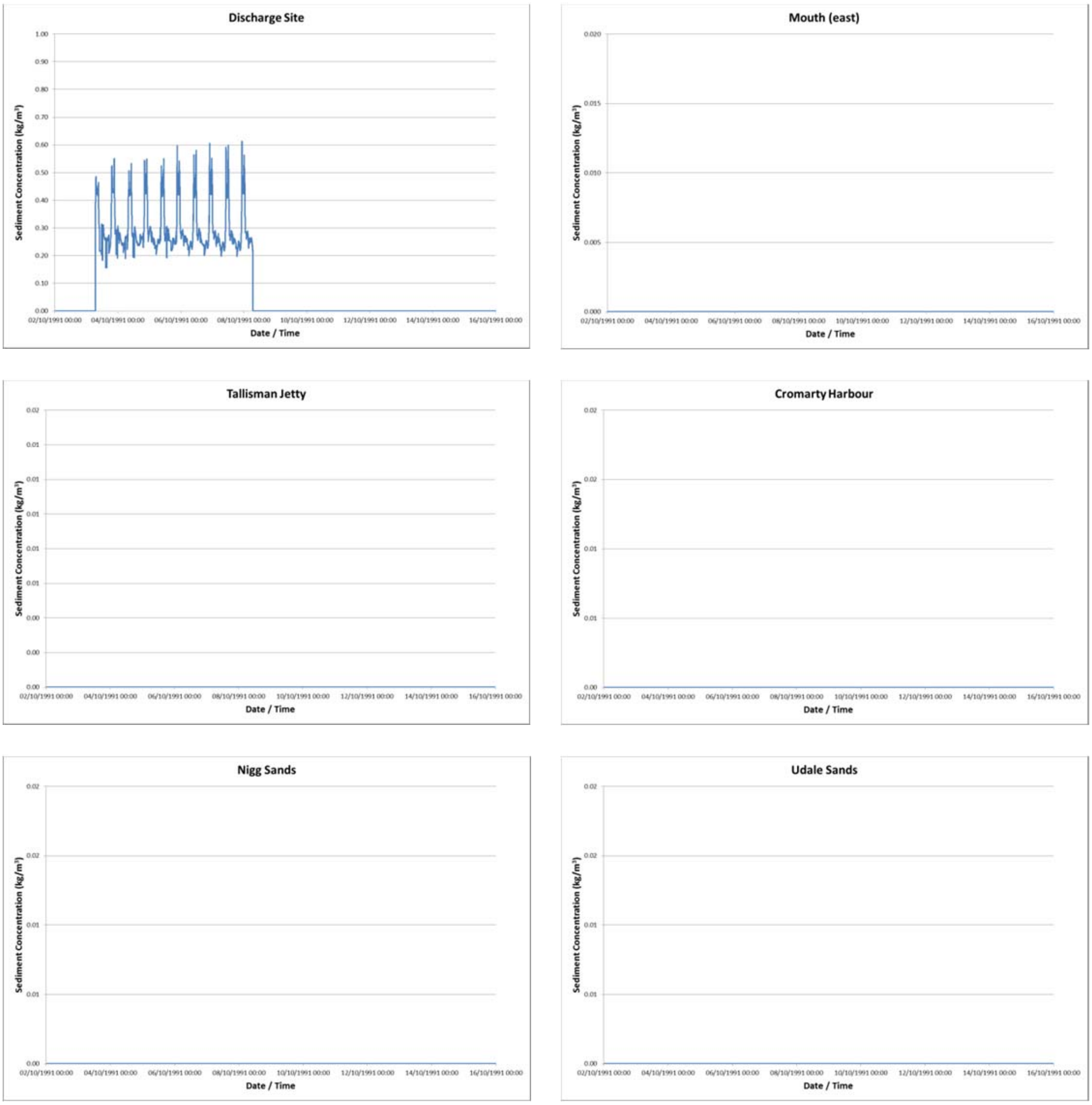


Figure 5 – Scenario 1: Enhanced SSC Values at Various Locations

3.3 Scenario 3 Modelling Results

Results in **Appendix C** are plotted at hourly intervals for the first 14 hours of the simulation of effects from a 'typical' wave event. This covers the duration of the storm (12.5 hours) plus a sufficient period thereafter for the elevated suspended sediment concentrations to return to notional background values.

A localised sediment plume is created immediately upon release of the material that becomes eroded by 'typical' wave action. However, the concentrations are much lower than for Scenario 2, typically being in the range 1-30mg/l and having a short-lived peak at around 50mg/l. The suspended sediment concentrations return to notional background levels within 14 hours of release.

Figure 6 shows that at the discharge site at which the eroded sediment from a 'typical' wave event of 12.5 hours duration is released into the model, the suspended sediment concentrations become elevated for around 13.0 hours. This shows that the effects of sediment loss from the berm due to 'typical' wave conditions are temporary. The magnitude of change in suspended sediment concentrations is very low, with elevated values ranging from typically 25mg/l to 50mg/l, depending on the stage of the tidal cycle. Elevated suspended sediment concentrations are recorded at none of the other five sites selected from around the wider Cromarty Firth. These results demonstrate that the erosion losses from the construction berm during 'typical' wave conditions will have temporary, localised and very low magnitude effects only.

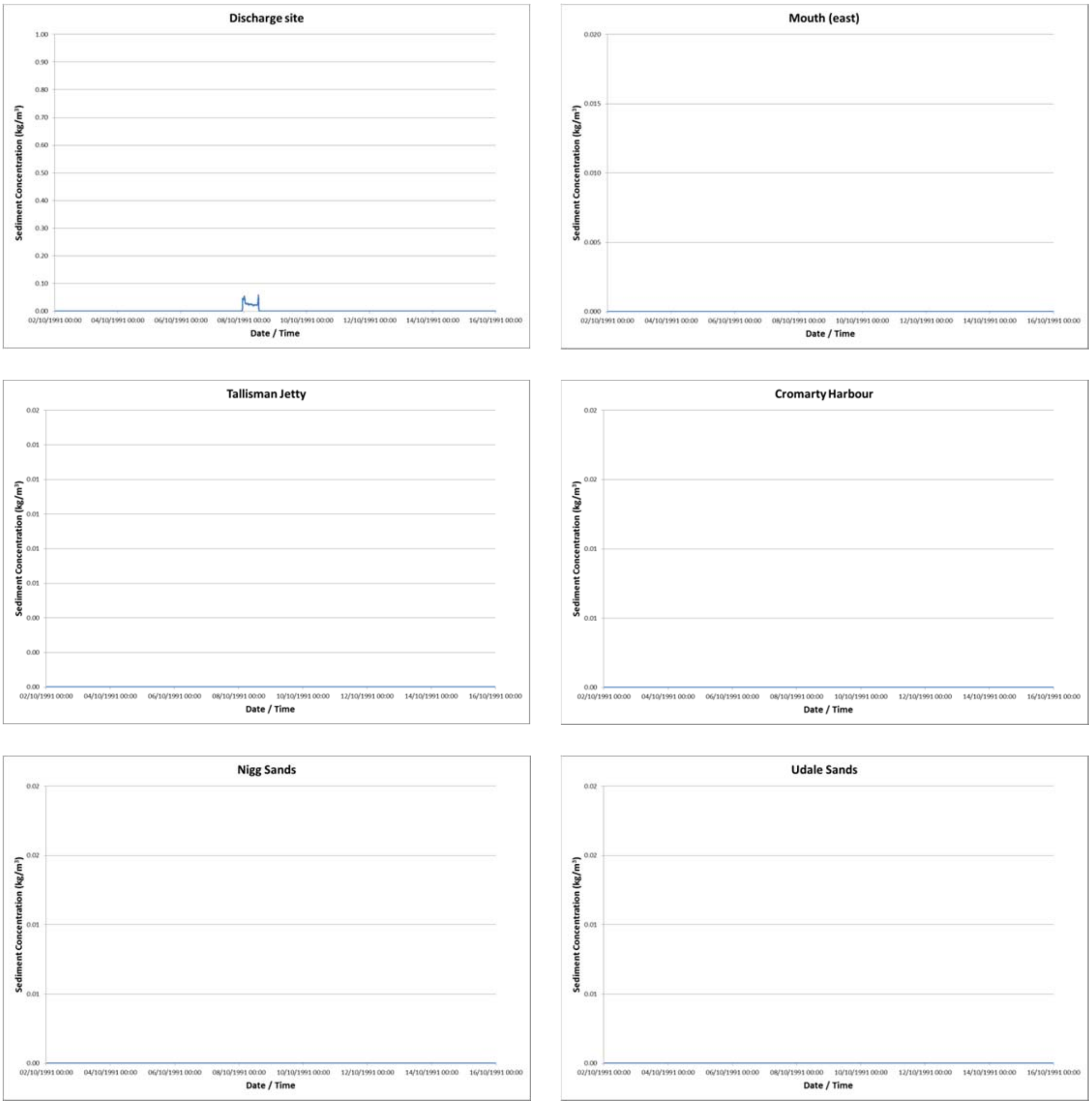


Figure 6 – Scenario 2: Enhanced SSC Values at Various Locations

3.4 Scenario 4 Modelling Results

Results in **Appendix D** are plotted at hourly intervals for the first 14 hours of the simulation of effects from a 'storm' wave event. This covers the duration of the storm (12.5 hours) plus a sufficient period thereafter to enable the elevated suspended sediment concentrations to return to notional background values.

A localised sediment plume is created immediately upon release of the material that becomes eroded by 'storm' wave action. The concentrations of sediment within the plume are slightly greater than for Scenario 3, but still remain much lower than for Scenario 2. Typically elevations in concentration are in the range 1-60mg/l but short-lived peaks of up to 80mg/l are observed on occasion. The suspended sediment concentrations return to notional background levels within 14 hours of release.

Figure 6 shows that at the discharge site at which the eroded sediment from a 'storm' wave event of 12.5 hours duration is released into the model, the suspended sediment concentrations become elevated for around 13.0 hours. This shows that the effects of sediment loss from the berm due to 'storm' wave conditions are temporary. The magnitude of change in suspended sediment concentrations is low, with elevated values ranging from typically 40mg/l to 80mg/l, depending on the stage of the tidal cycle. Elevated suspended sediment concentrations are recorded at none of the other five sites selected from around the wider Cromarty Firth. These results demonstrate that the erosion losses from the construction berm during 'typical' wave conditions will have temporary, localised and low magnitude effects only.

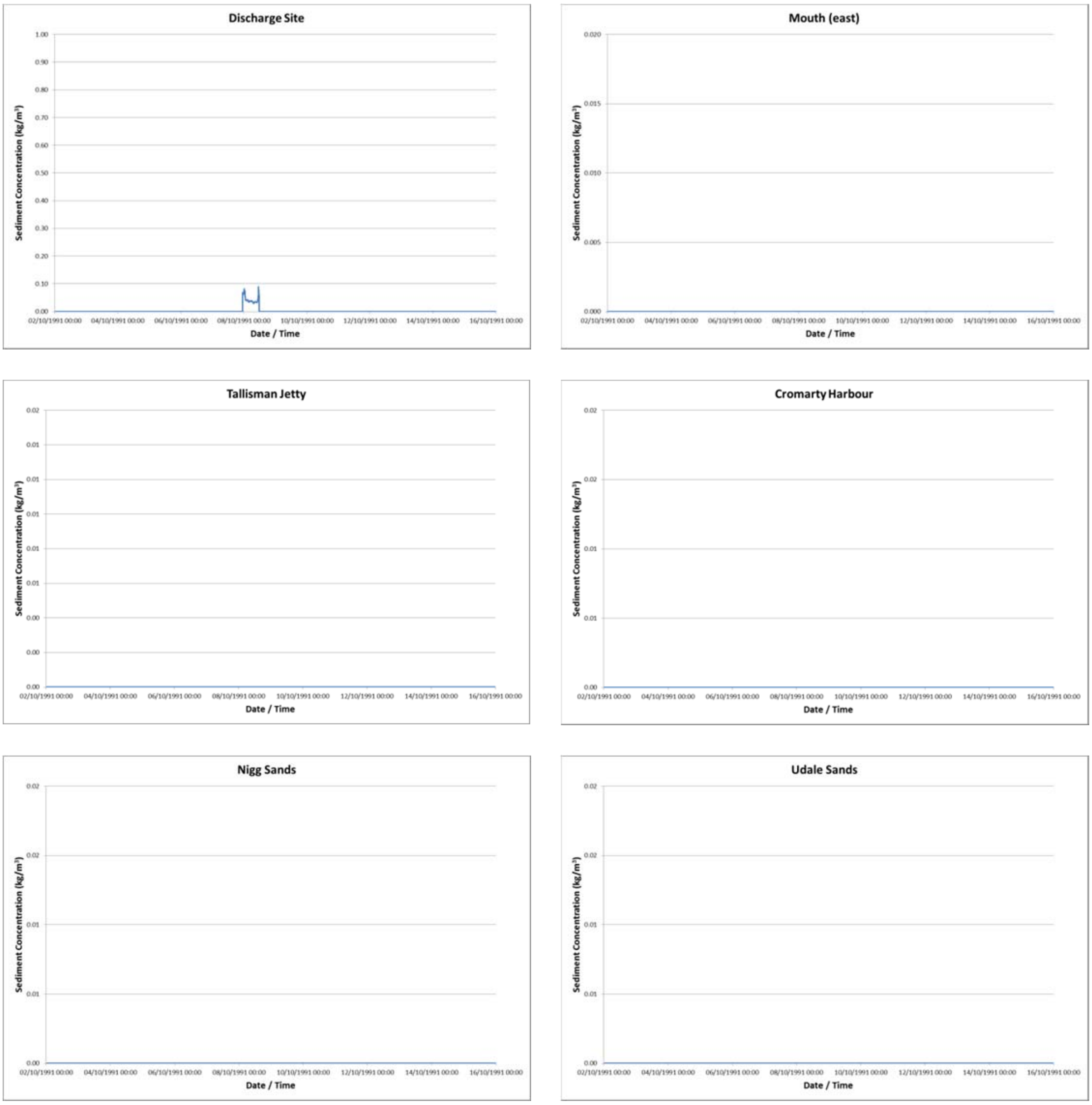


Figure 6 – Scenario 2: Enhanced SSC Values at Various Locations

3.5 Scenario 5 Modelling Results

The effects of spillage losses from the final sea bed dredging activities and the disposal activities at The Sutors spoil ground were addressed within the previous sediment plume and sediment deposition modelling studies. These were reported in Section 7 of the previous modelling report (Royal HaskoningDHV, 2013).

4 CONCLUSIONS

Modelling has shown that the effects of the alternative construction method using a berm created from dredged material are temporary in duration and, other than very locally to the point of discharge, are small in magnitude. Effects arising from construction of the berm are very much greater than effects arising from the loss of material from exposed sections of the berm during 'typical' or 'storm' wave conditions. Effects from the additional modelling the alternative construction method are less than the effects previously assessed from the disposal of dredged material at The Sutors spoil ground.

Immediately at the point of discharge of the dredged material into the water column during construction of the berm, the elevation in suspended sediment concentrations will be high (up to 600mg/l) but even this localised effect is temporary in duration, with values returning to notional background levels very soon after cessation of activities.

If these temporary and localised changes in suspended sediment concentration are deemed unacceptable in an environmental context, then mitigation in the form of silt screens may be a necessary consideration.

5 REFERENCES

Royal HaskoningDHV, 2013. *Nigg Energy Park: Sedimentation and Wave Modelling (Main Report & Appendices)*. May 2013. Report to Global Energy Nigg Ltd.

APPENDIX A

LITPROF MODELLING OF EROSION FROM THE CONSTUCTION BERM

LITPROF MODELLING OF EROSION FROM THE CONSTUCTION BERM

1. Introduction

This appendix describes the cross-shore profile modelling of berm stability under 'typical' and 'storm' wave activity during the construction period. The modelling was undertaken using LITPROF, a computational module of the LITPACK software, which was developed by the Danish Hydraulic Institute.

LITPROF describes the cross-shore profile changes based on a time series of wave and water level events. The model is based on the assumption that longshore variations in hydrodynamic and sediment conditions are negligible and that the depth contours are parallel to the coastline. Thus the berm morphology is described solely by a single cross-shore profile.

2. Model Settings & Input conditions

The following model settings and input parameters were used in the LITPROF modelling.

- The berm slope is V:H = 1:6
- The seaward face (only) of the berm was represented in the model (see Figure A1)
- The sediment in the berm is predominantly non-cohesive sediment, with a median grain size diameter (d_{50}) of 0.28mm
- The sediment gradation coefficient, σ, is defined by $(d_{84}/d_{16})^{0.5}$
  - A value of σ = 1.35 was used in the base case
  - A value of σ = 2.0 was used in a sensitivity test
- The sediment porosity was set at 0.4
- The wave theory used was Stoke's second-order
- Tidal elevations were extracted from the Nigg MIKE21 hydrodynamic model (see Figure A2 and Figure A3)
- Wave parameters were extracted from the Nigg MIKE21-SW wave transformation model

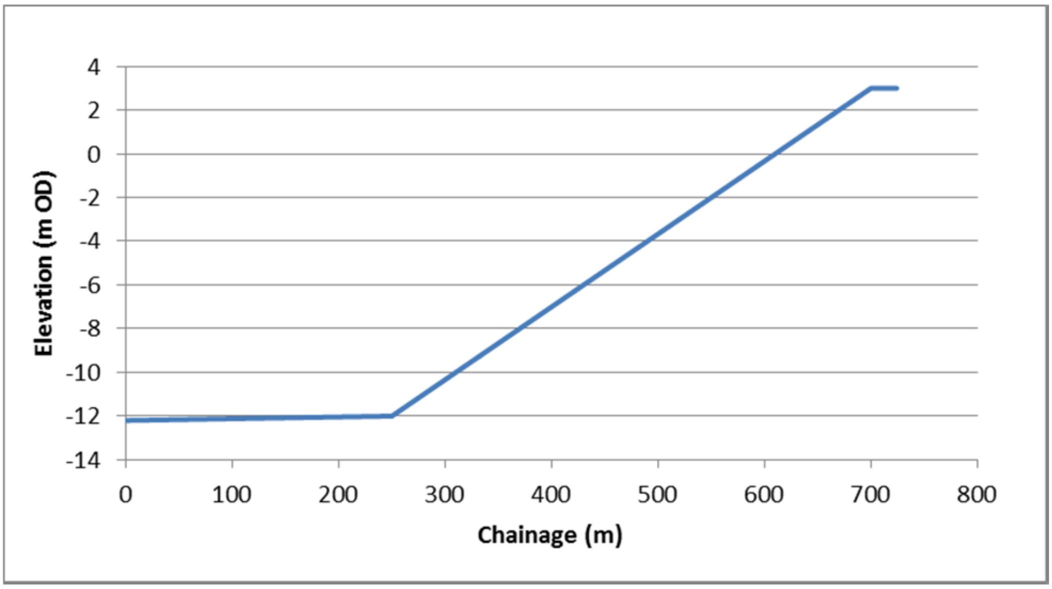


Figure A1: Berm profile

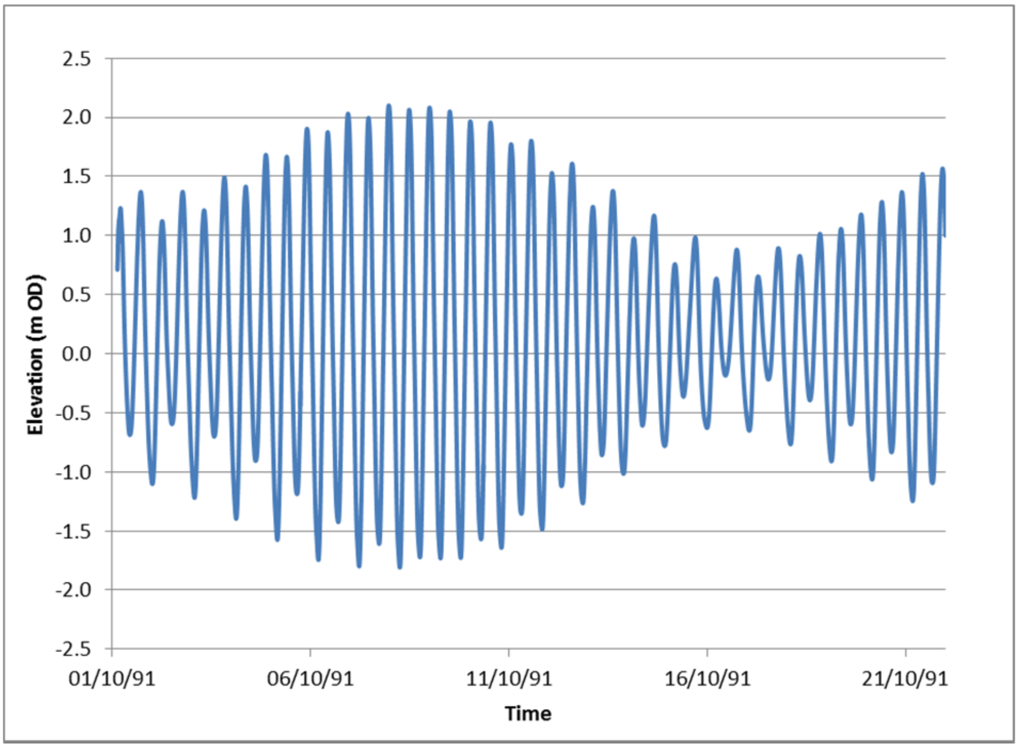


Figure A2: Tidal elevations at Nigg Energy Park

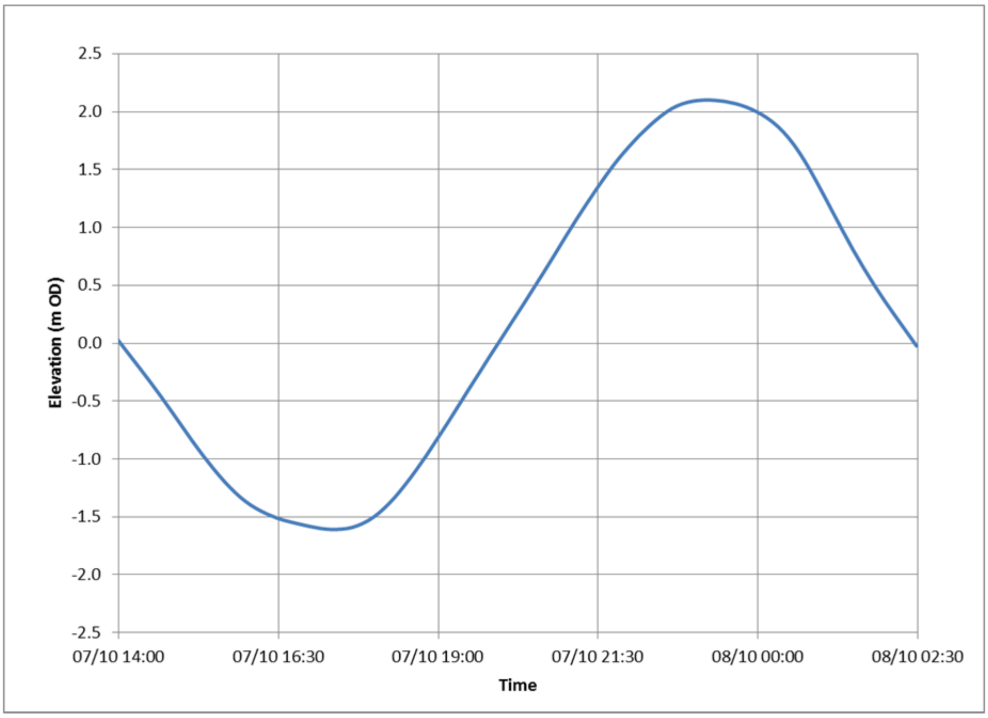


Figure A3: Tidal elevation used for storm conditions (12.5 hours)

3. Run scenarios

The following runs were undertaken using the LITPROF model:

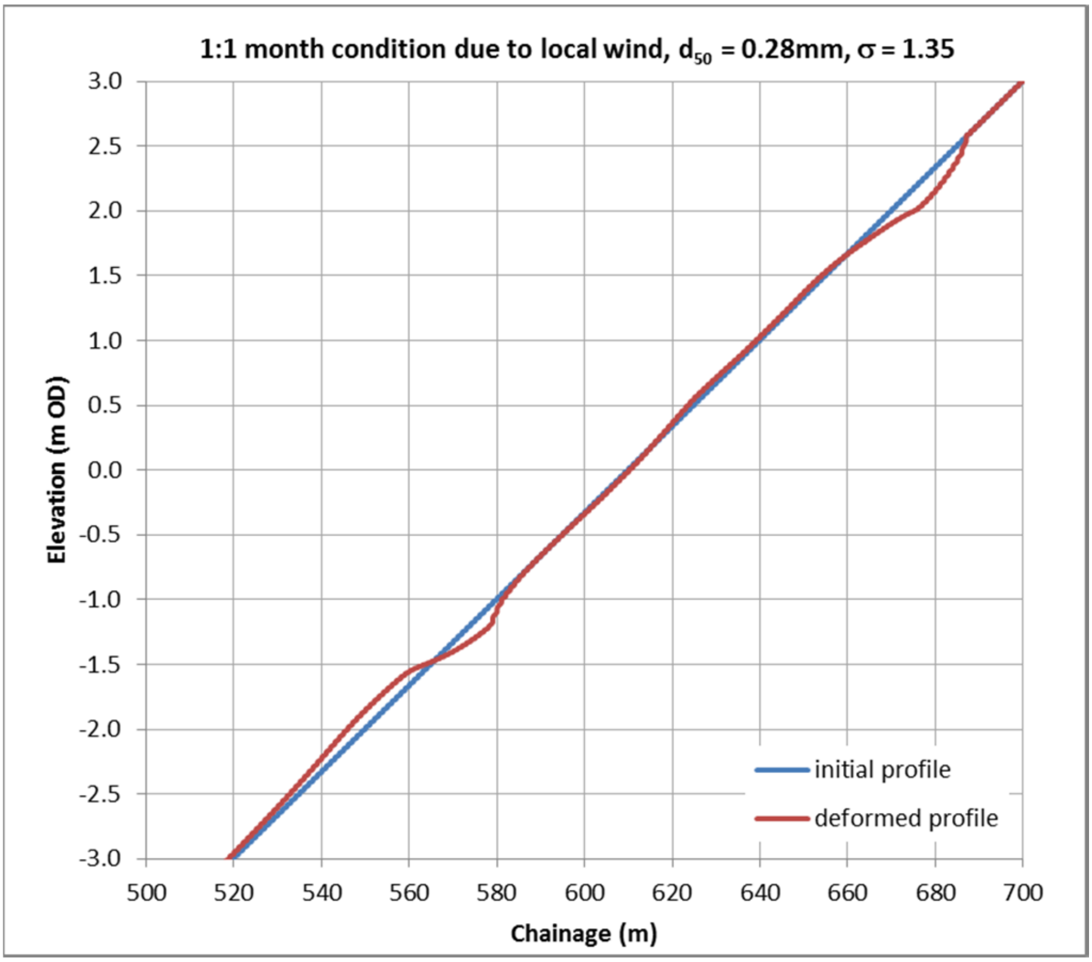
Run	Description	H_s (m)	T_m (s)	Mean Direction (°N)	Duration (hours)
1	1:1 month condition for waves by local SW wind	0.60	3.0	242	12.5
2	1:1 month condition for waves from North Sea	0.60	4.2	120	12.5
3	1:1 year condition for waves by local SW wind	0.92	3.0	245	12.5
4	1:1 year condition for waves from North Sea	0.92	6.4	120	12.5

The base case for each run used a grading coefficient σ = 1.35

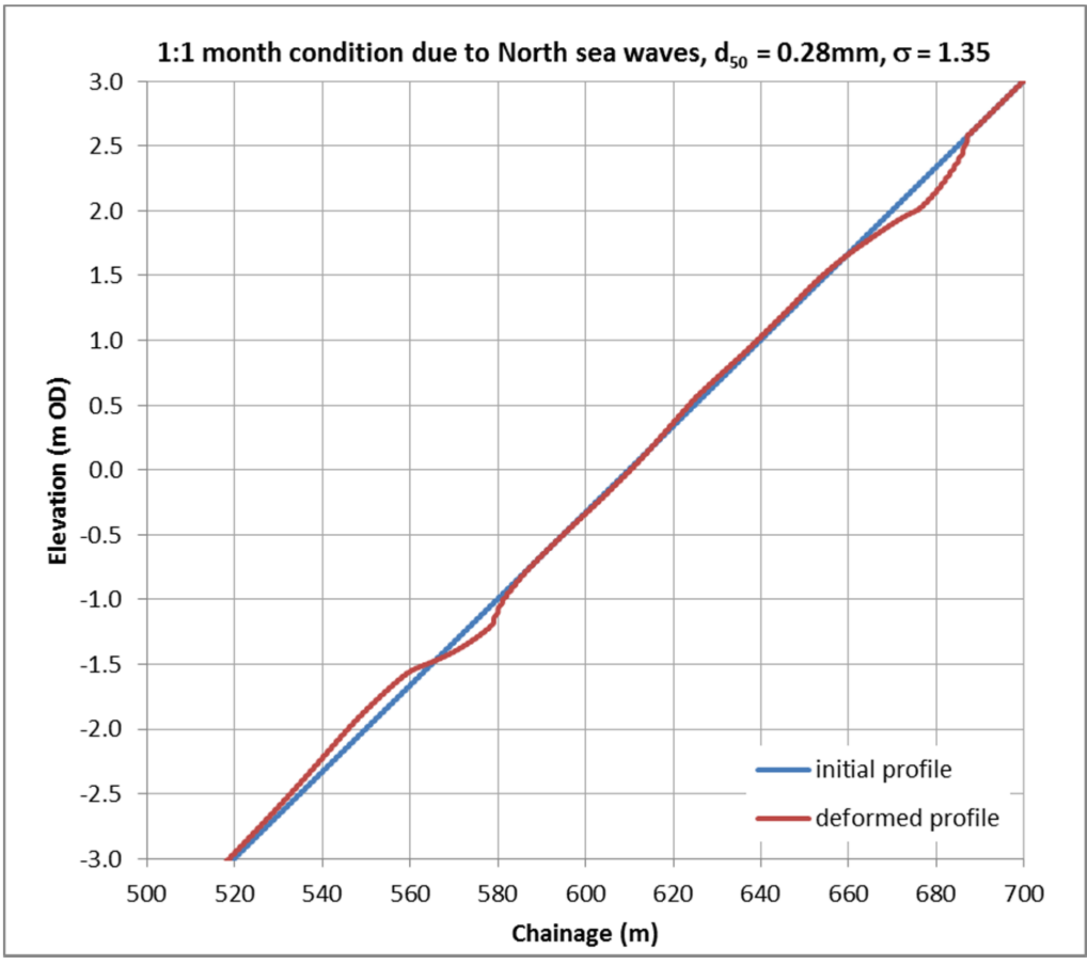
The sensitivity case for each run used a grading coefficient σ = 2.0

4. Results

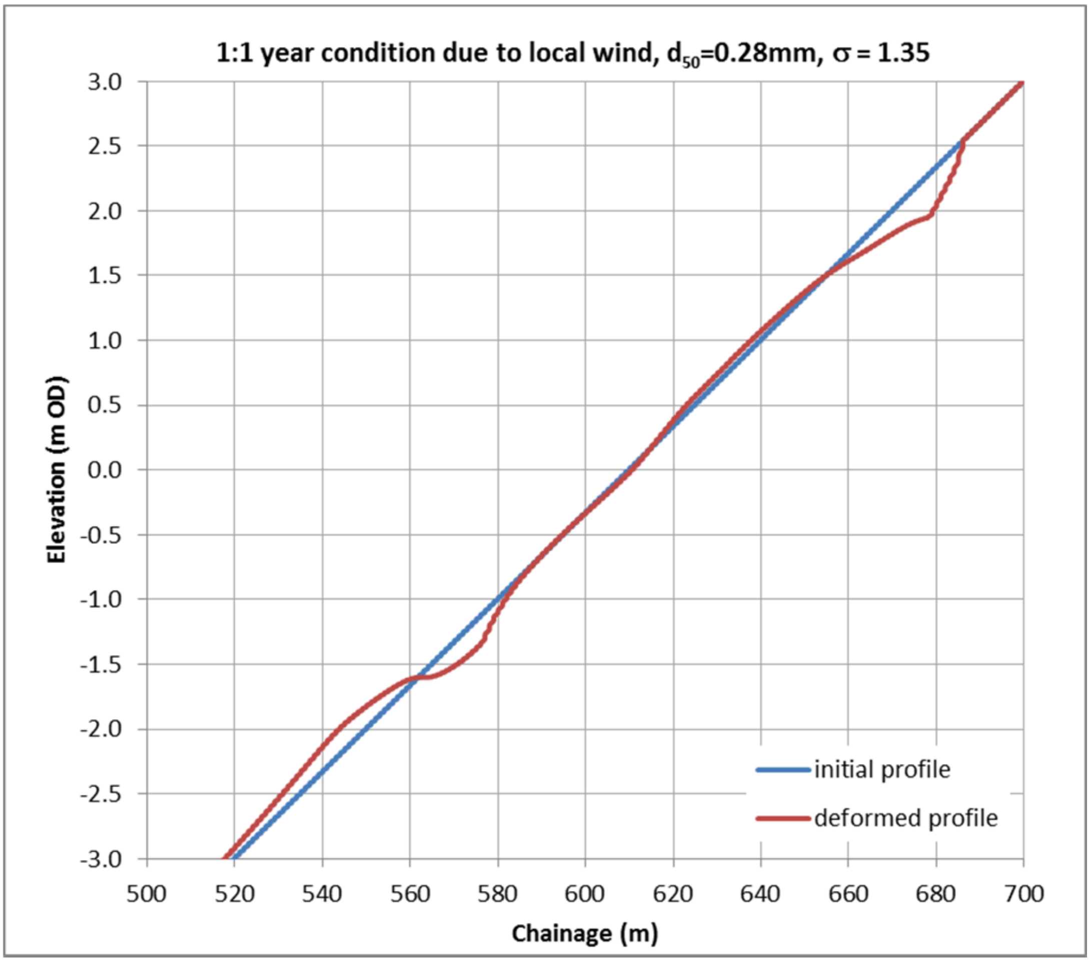
The model results are presented in the following plots. Deformations of the seaward slope of the berm concentrate at the low and high water marks, therefore for ease of observation the plots focus on this zone of the berm slope.



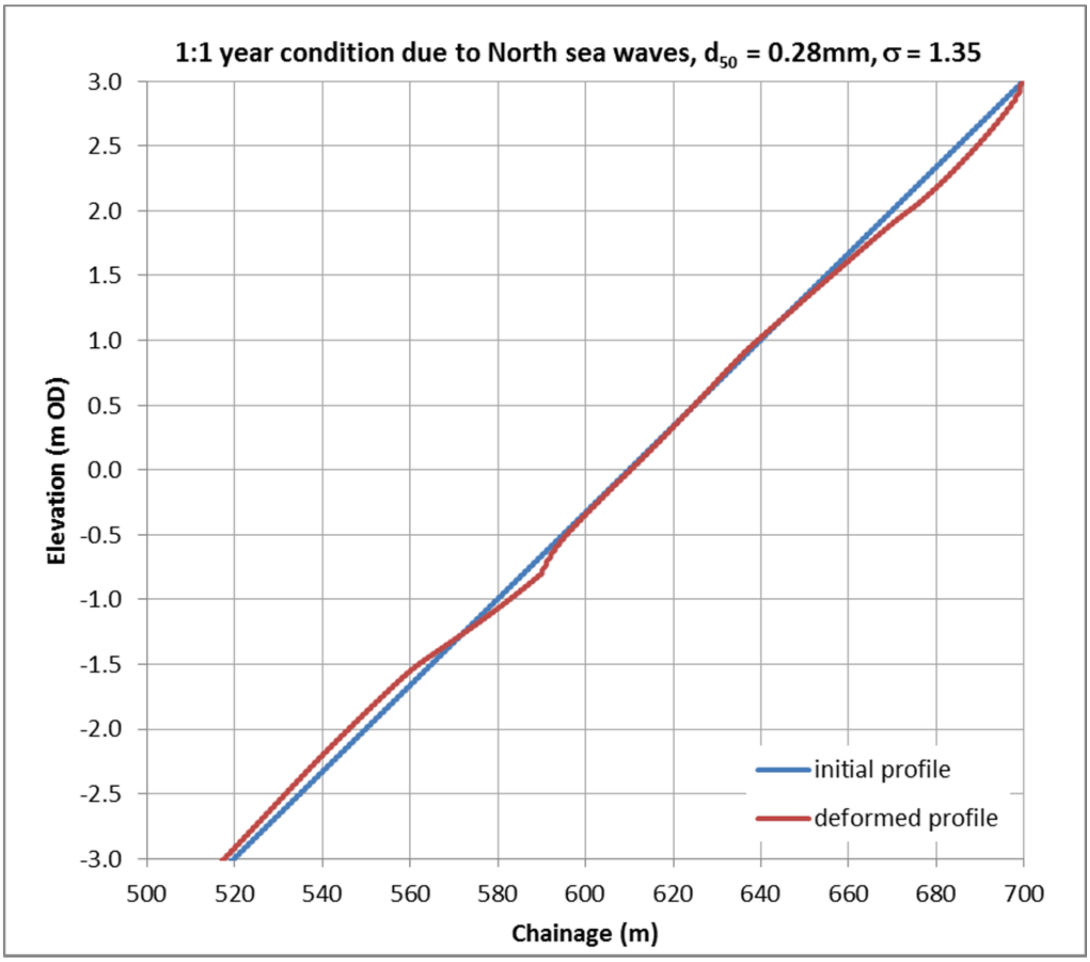
Plot 1 – Run 1 (σ = 1.35)



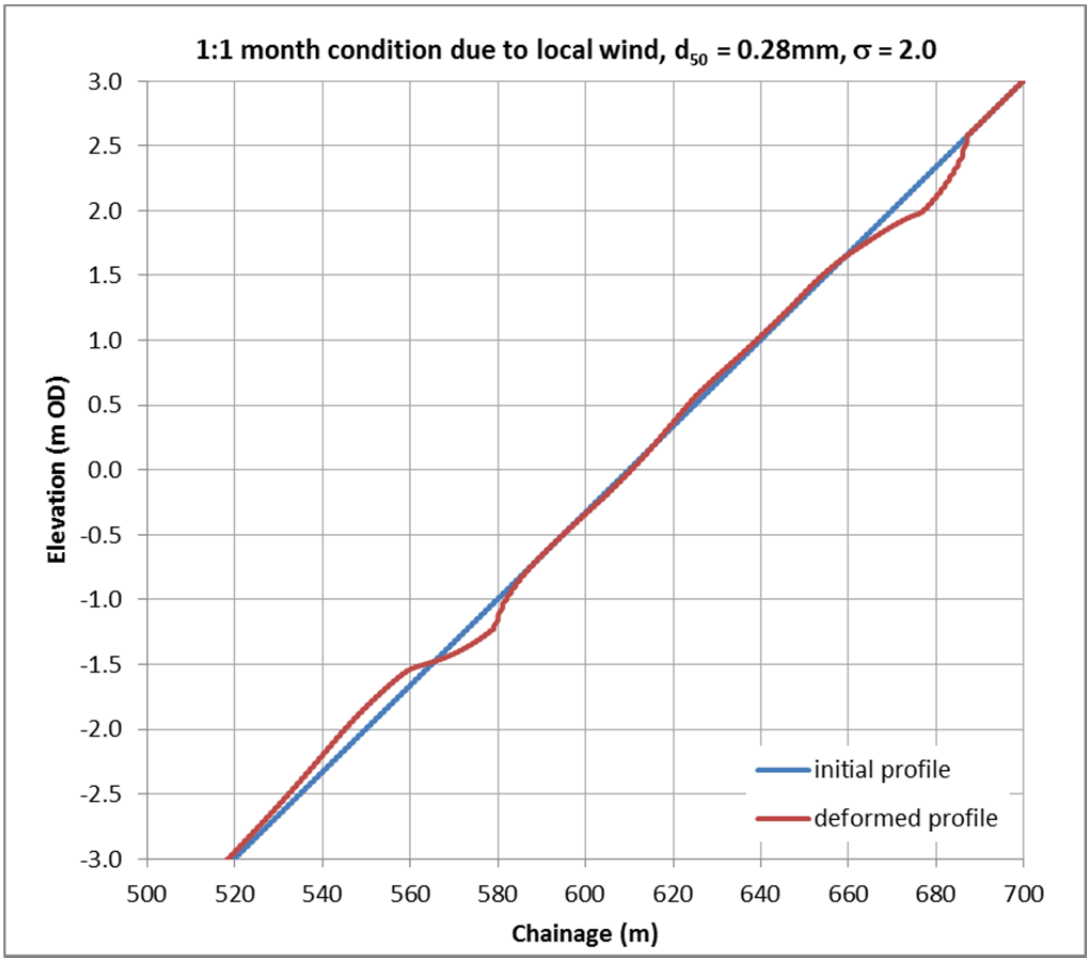
Plot 2 – Run 2 (σ = 1.35)



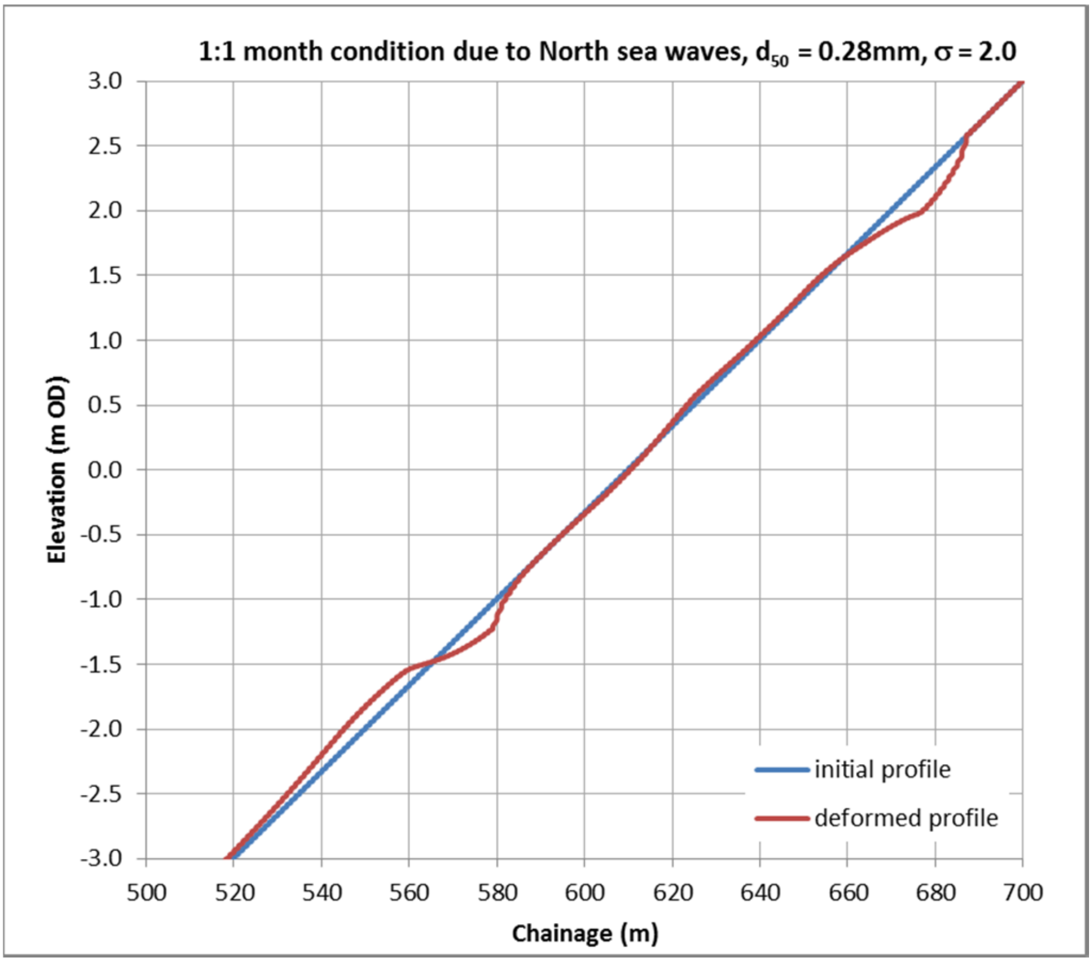
Plot 3 – Run 3 (σ = 1.35)



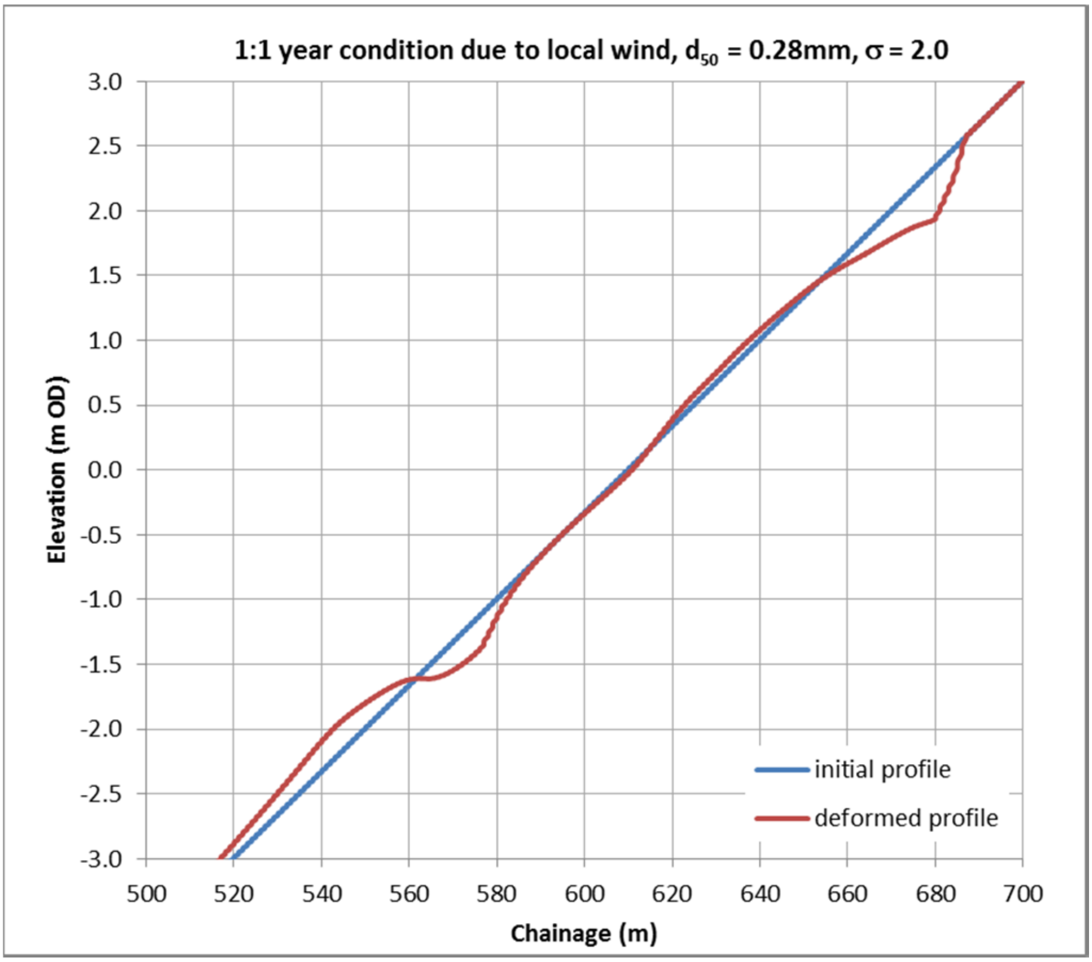
Plot 4 – Run 4 (σ = 1.35)



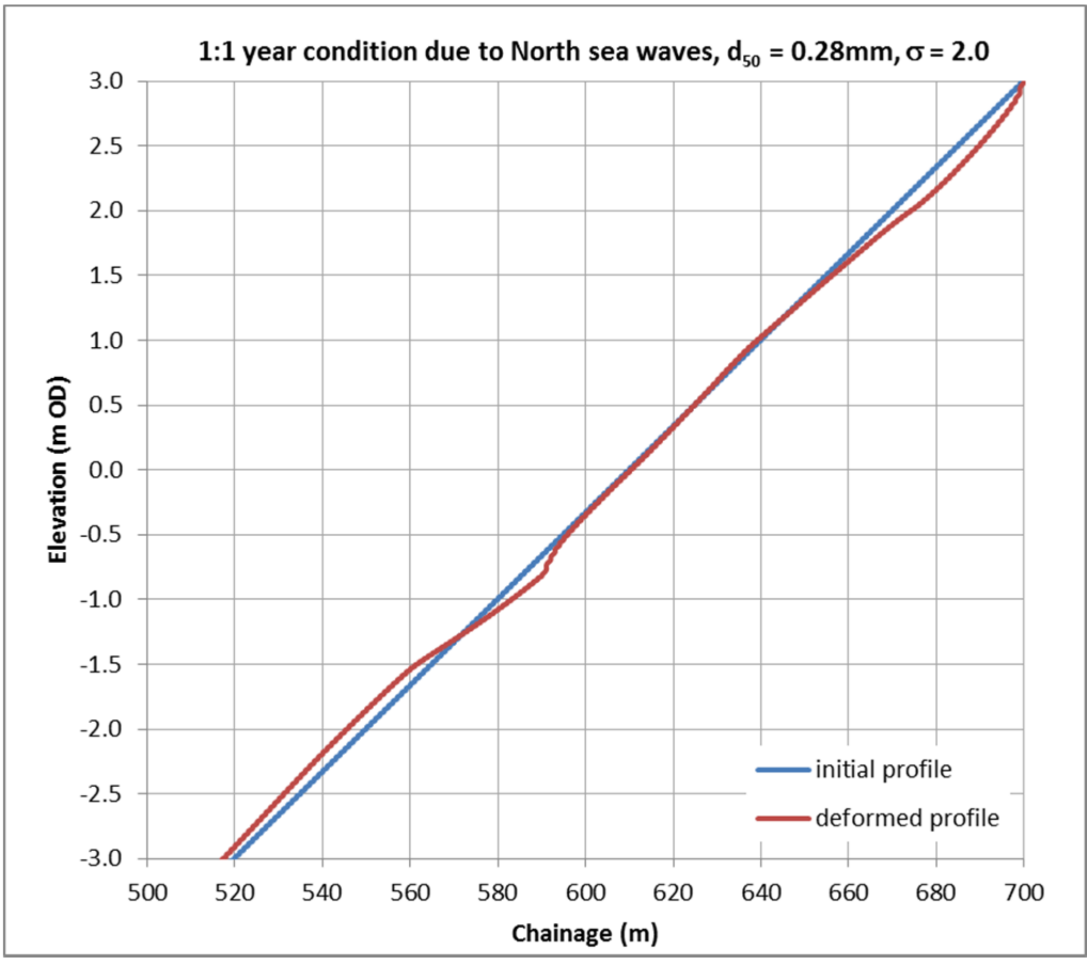
Plot 5 – Run 1 (σ = 2.00)



Plot 6 – Run 2 (σ = 2.00)



Plot 7 – Run 3 (σ = 2.00)



Plot 8 – Run 4 (σ = 2.00)

5. Conclusion

In each model run, there are some areas where sediment is eroded from the seaward face of the berm and deposited elsewhere on the seaward face of the berm. As a worst case assessment, it has been assumed that all sediment eroded from the berm has the potential to become entrained by the tidal currents (if they are sufficiently strong) and thus form a sediment plume. Therefore the total eroded area, per metre length of berm, is summarised in the table below

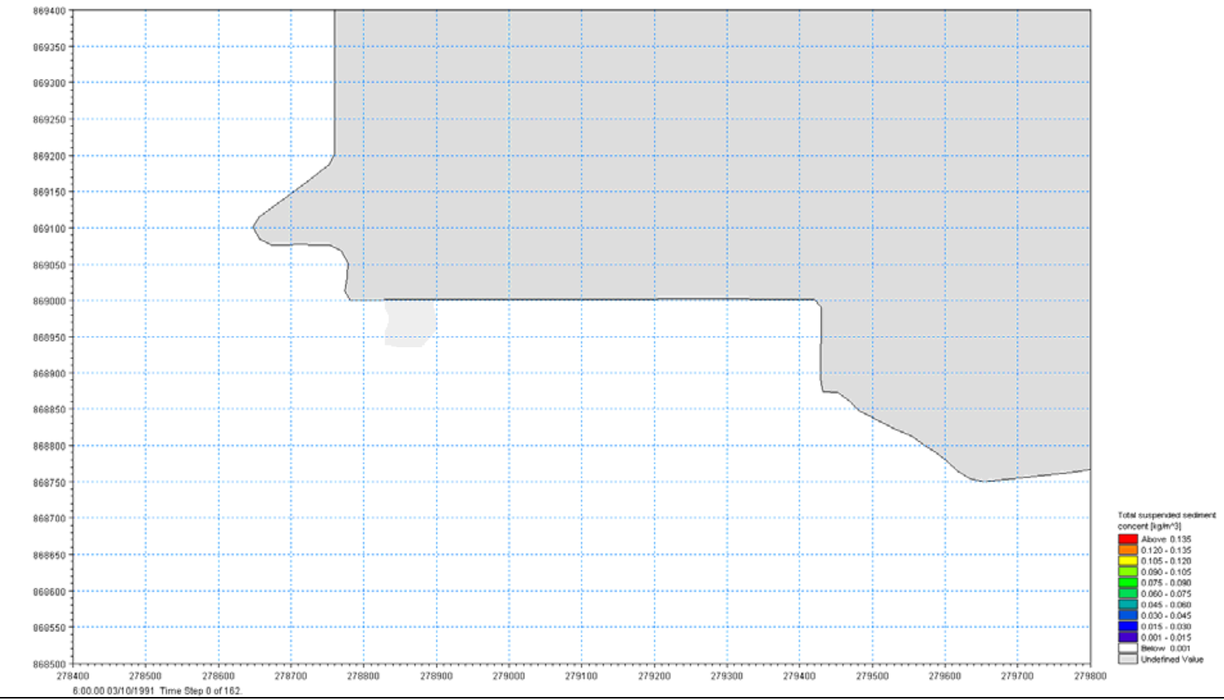
Run	Description	Eroded area (m^2/m) Base Case σ = 1.35	Eroded area (m^2/m) Sensitivity σ = 2.0
1	1:1 month condition for waves by local wind	4.8	6.1
2	1:1 month condition for waves from North Sea	4.8	6.1
3	1:1 year condition for waves by local wind	8.2	10.3
4	1:1 year condition for waves from North Sea	7.2	8.1

The model results suggest that the berm slope remains broadly stable under both the 'typical' and 'storm' wave conditions experienced. The most notable changes in the seaward face occur at around the high water and low water marks on the profile.

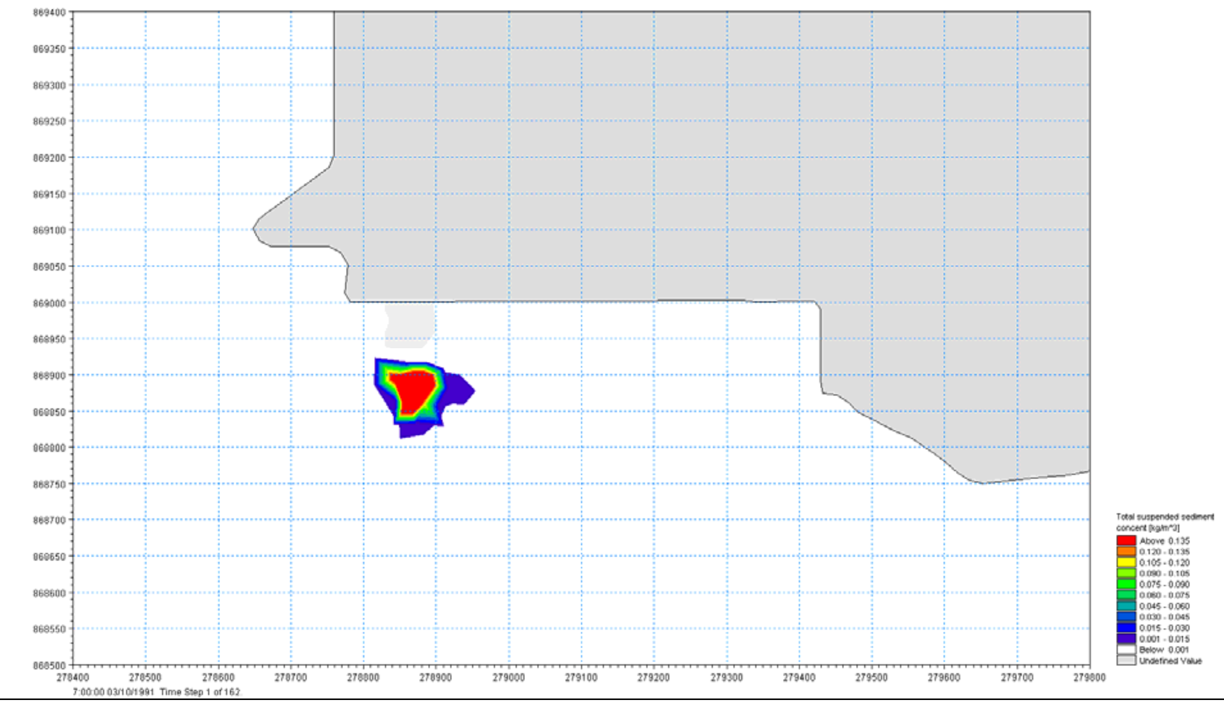
The sensitivity tests show that with a relatively small variation in the sediment gradation coefficient (σ), there can be an increase in the extent of material released due to erosion.

APPENDIX B

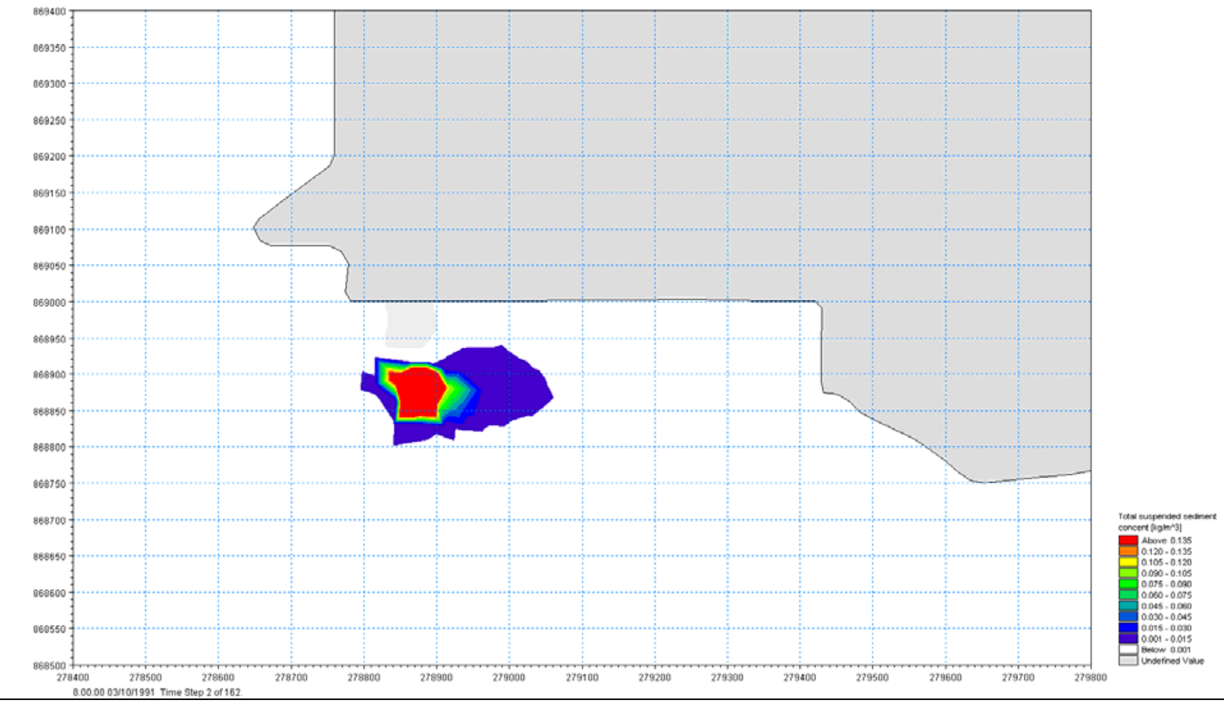
SCENARIO 2 MODELLING RESULTS



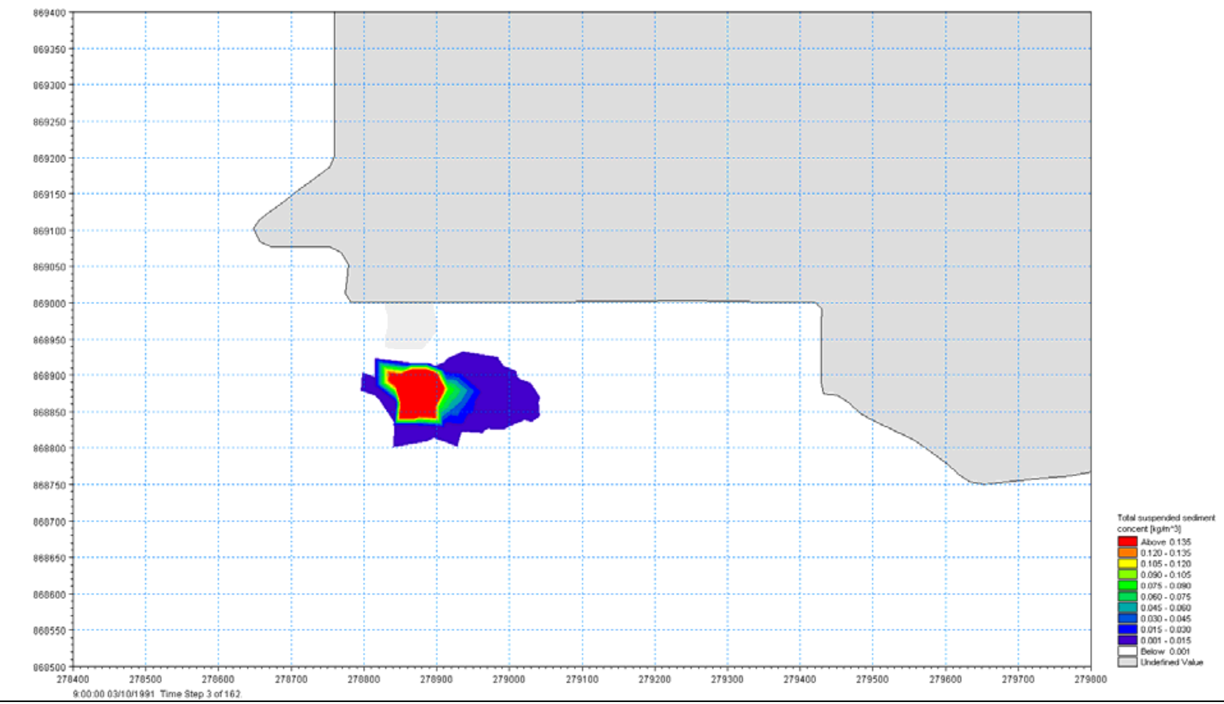
0 hours after start of release



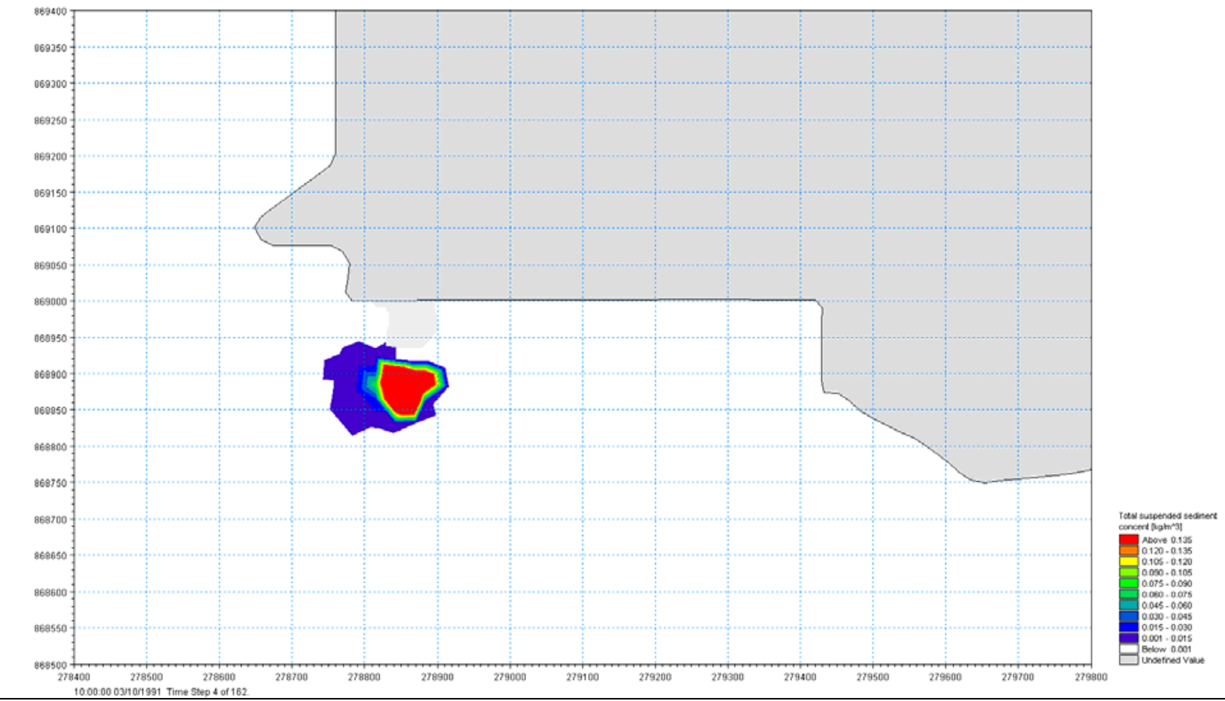
1 hour after start of release



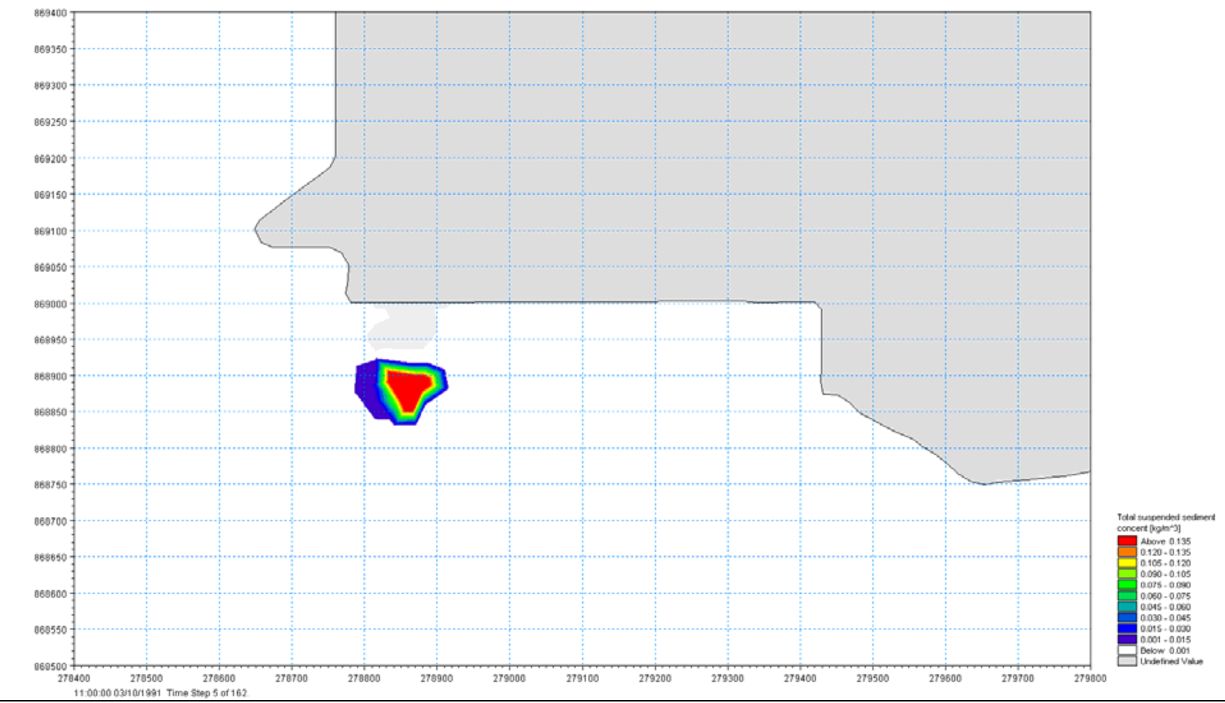
2 hours after start of release



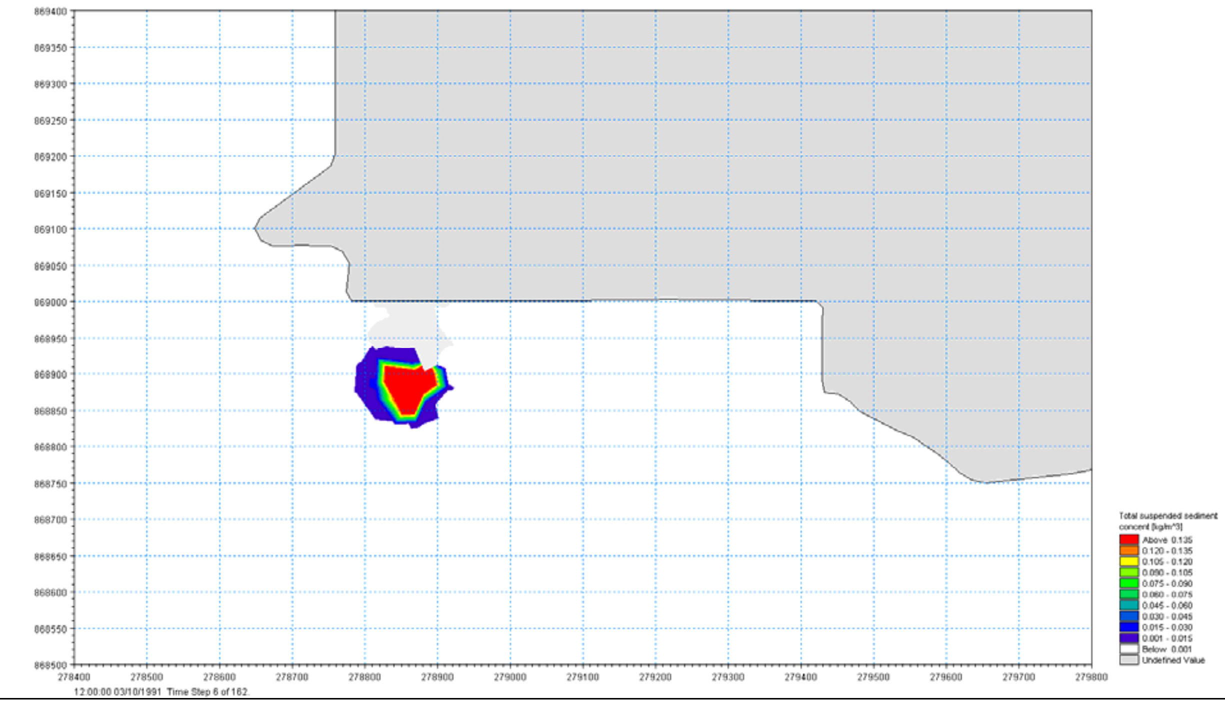
3 hours after start of release



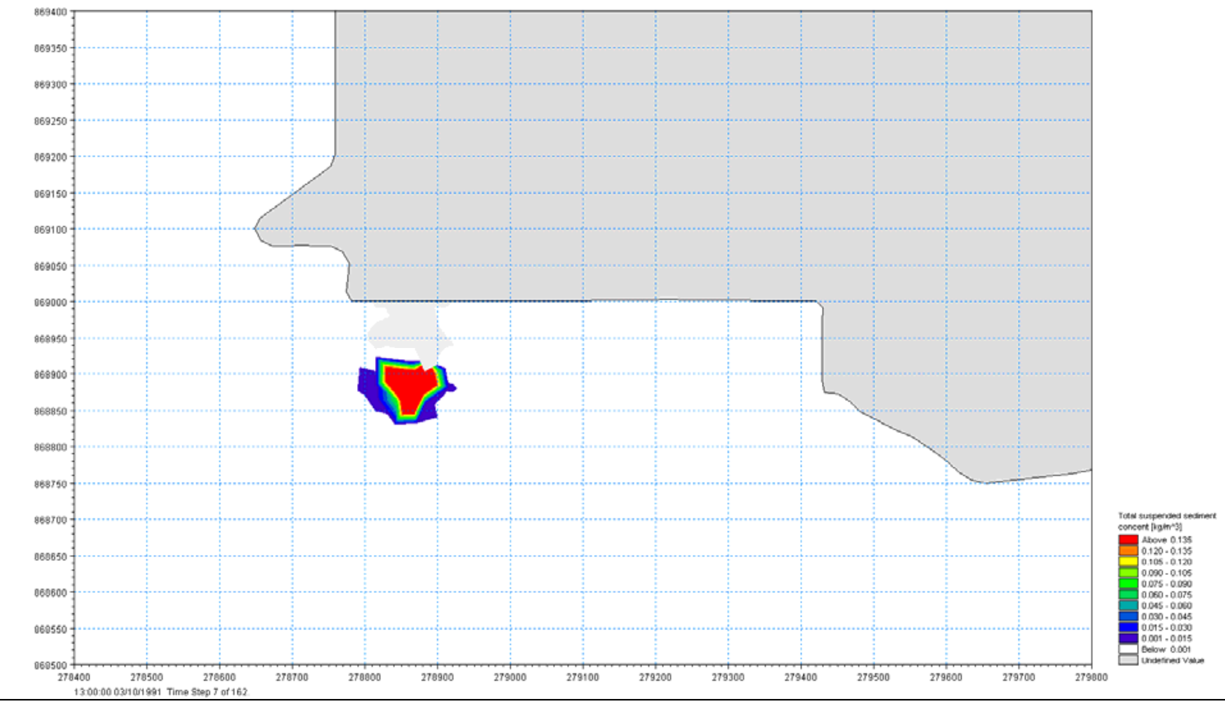
4 hours after start of release



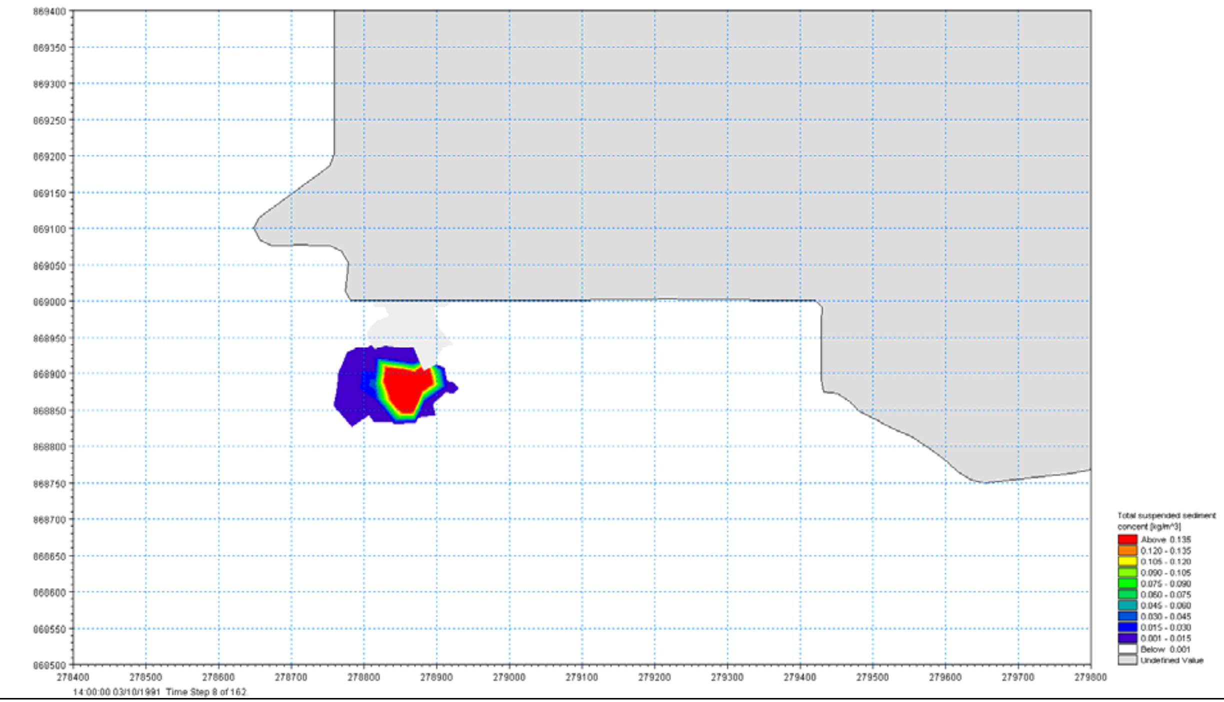
5 hours after start of release



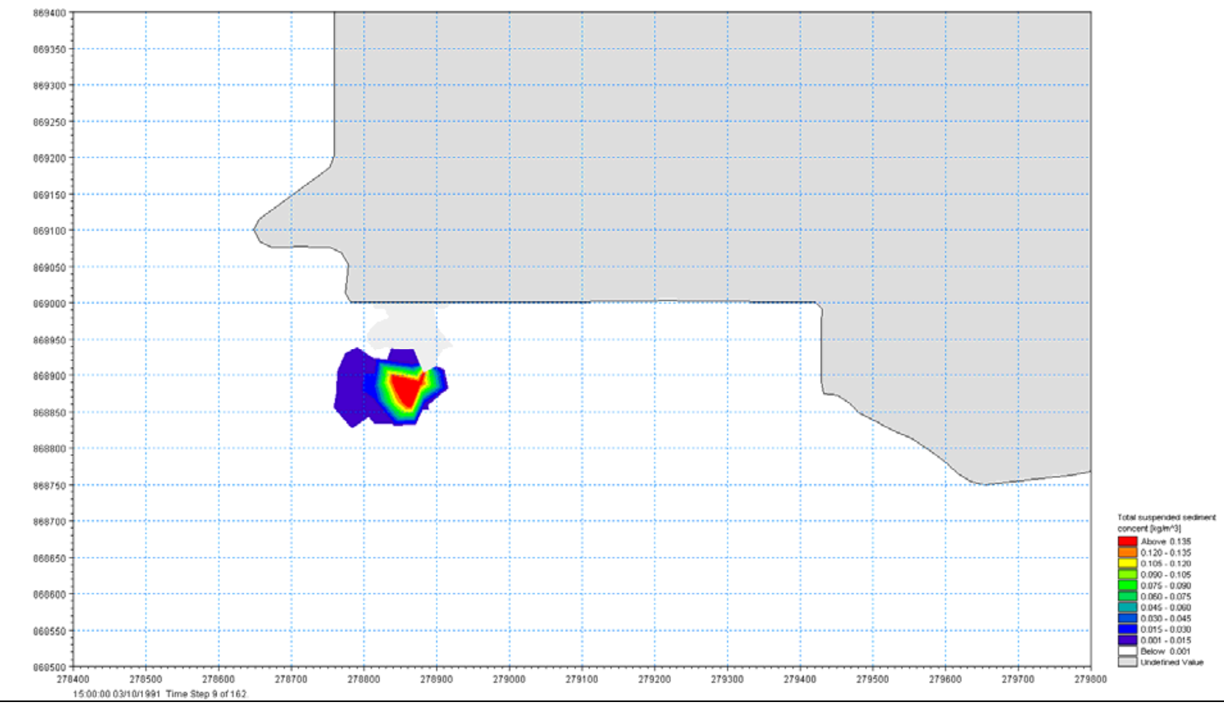
6 hours after start of release



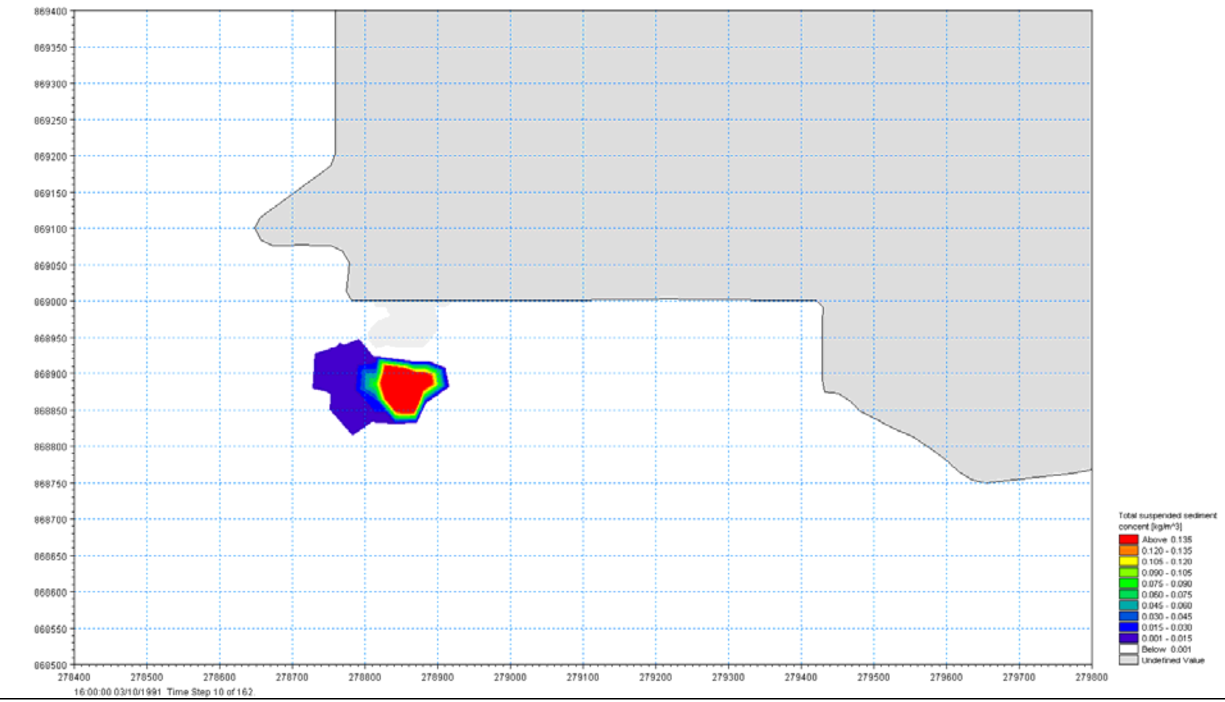
7 hours after start of release



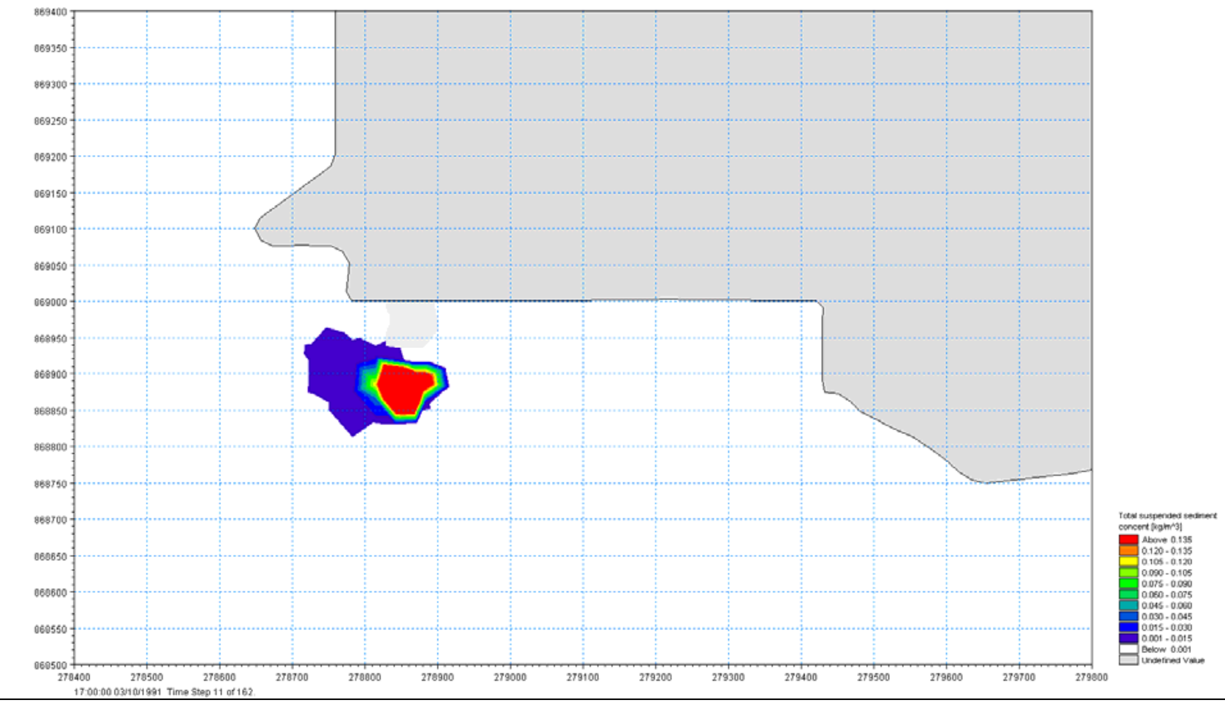
8 hours after start of release



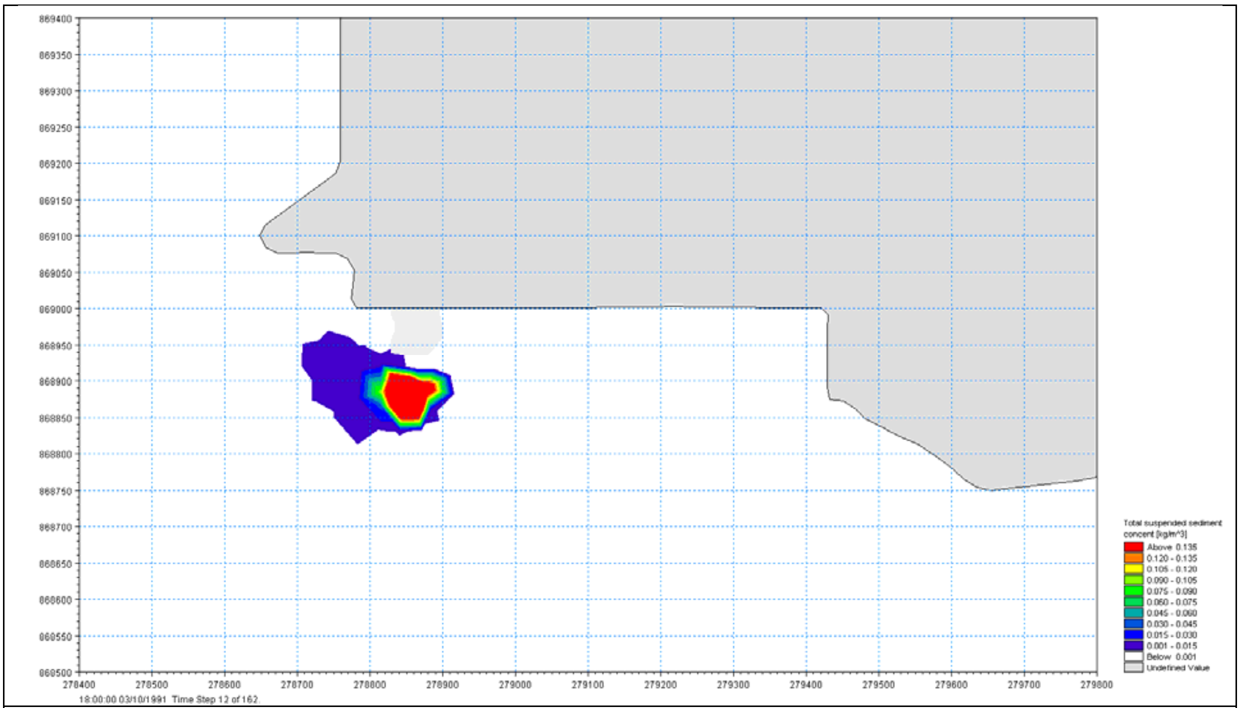
9 hours after start of release



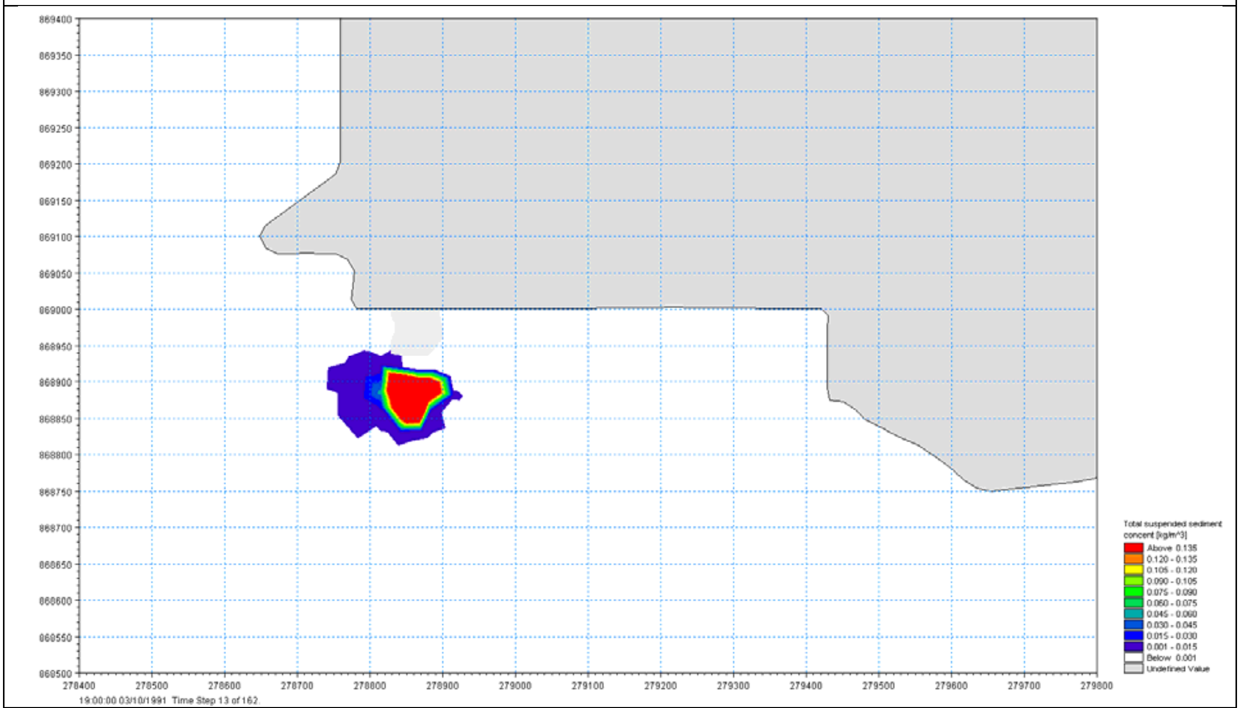
10 hours after start of release



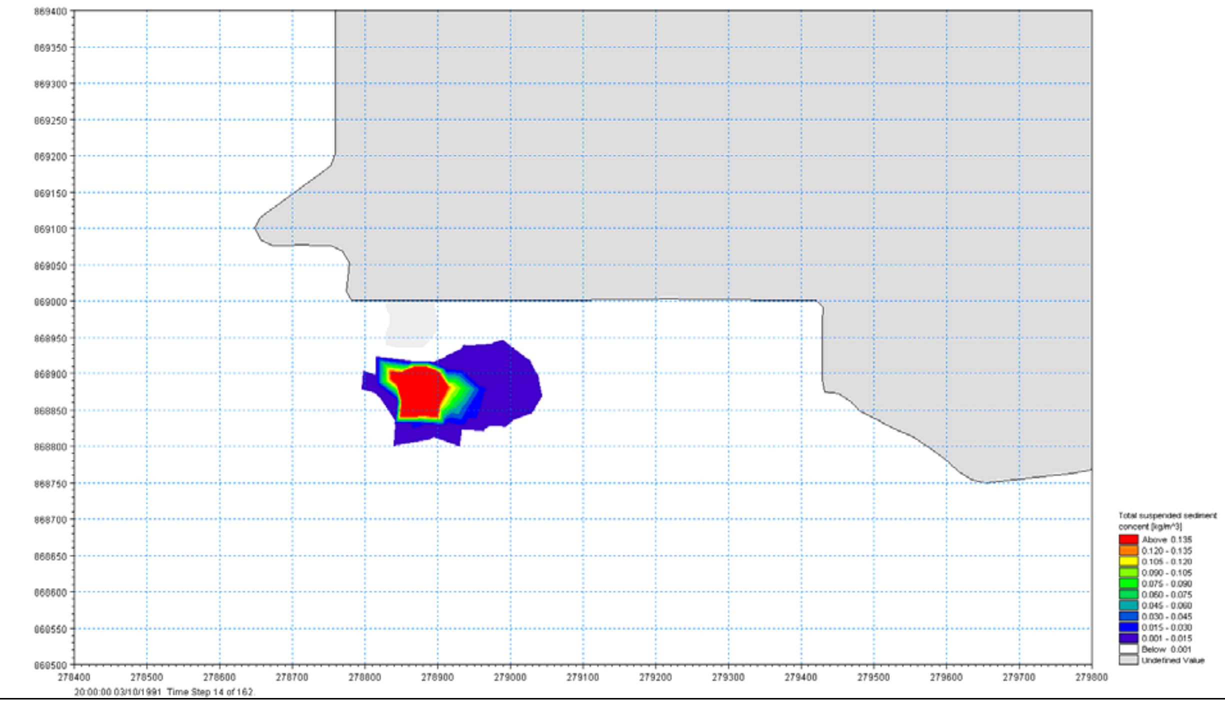
11 hours after start of release



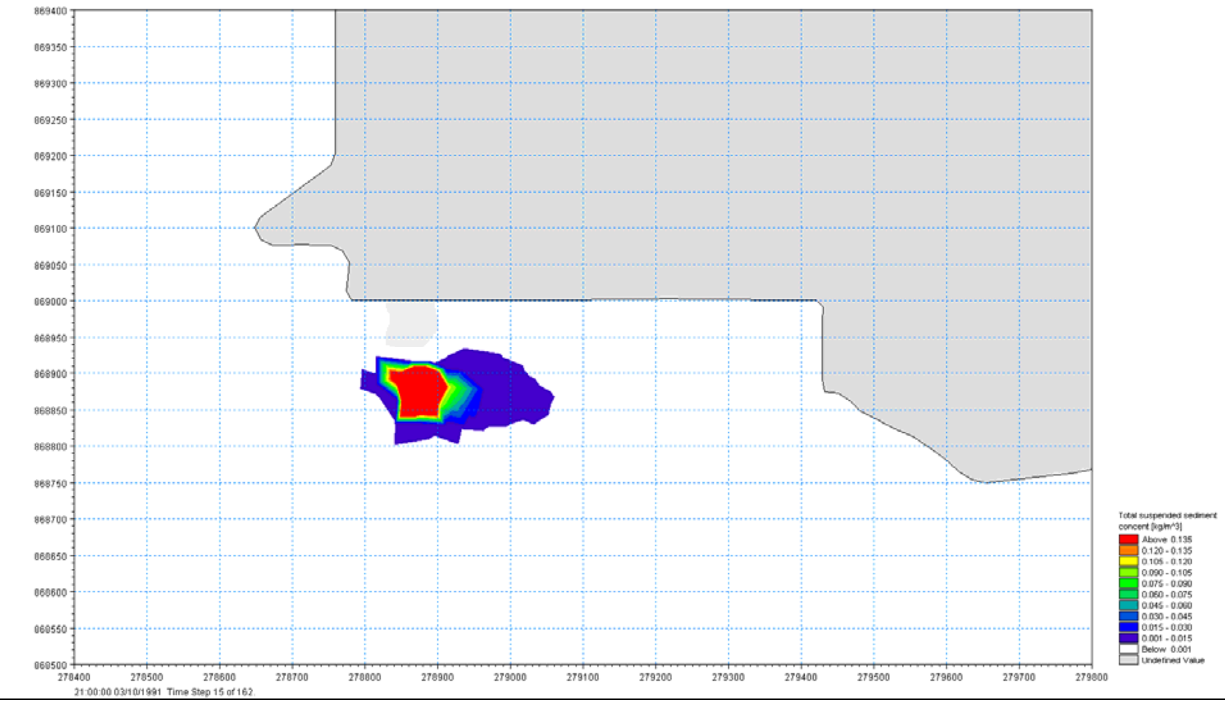
12 hours after start of release



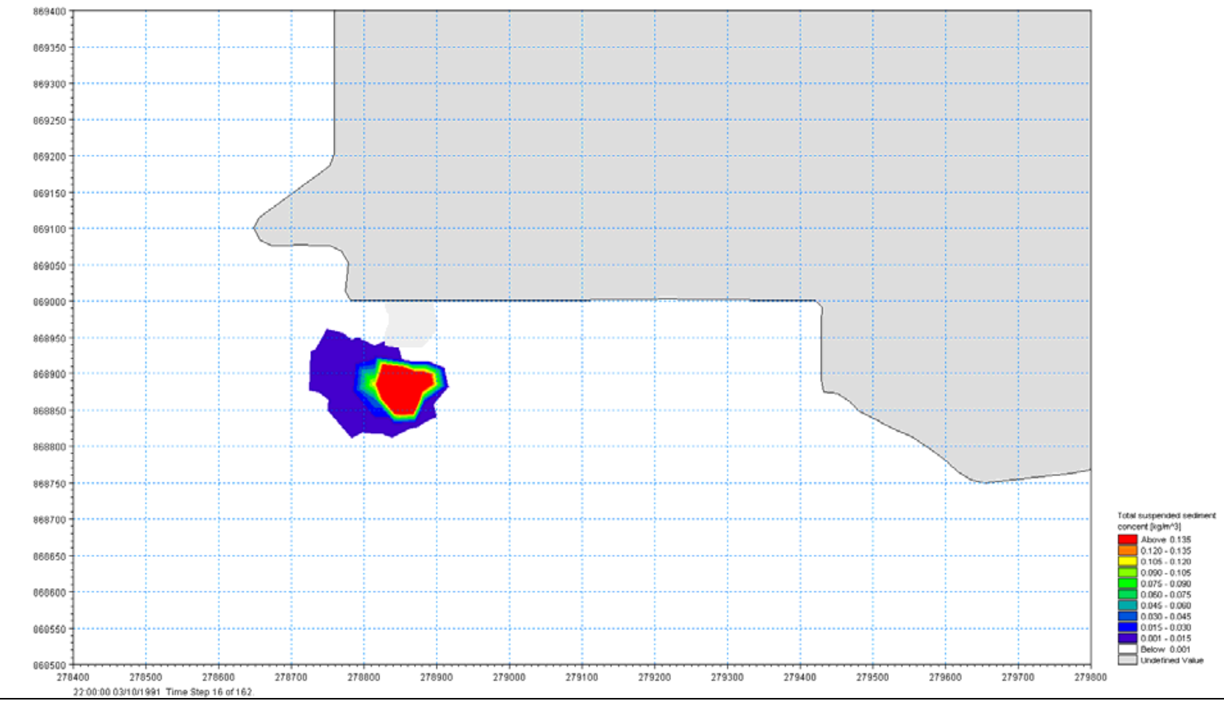
13 hours after start of release



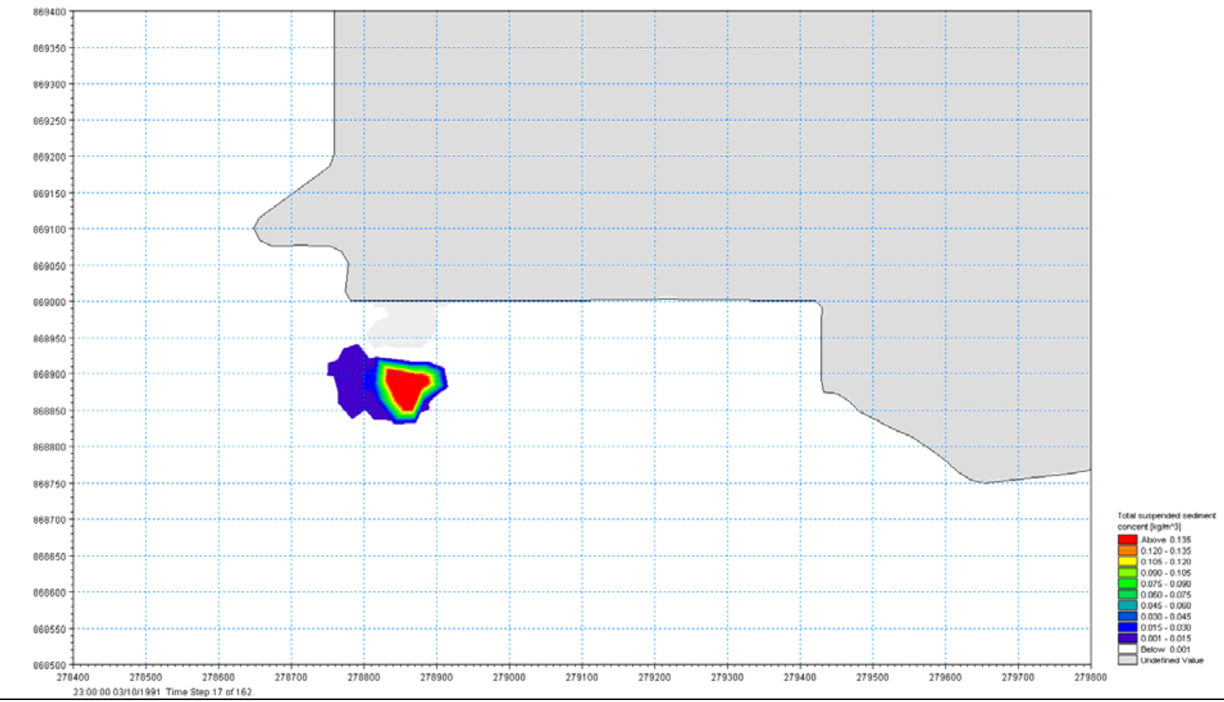
14 hours after start of release



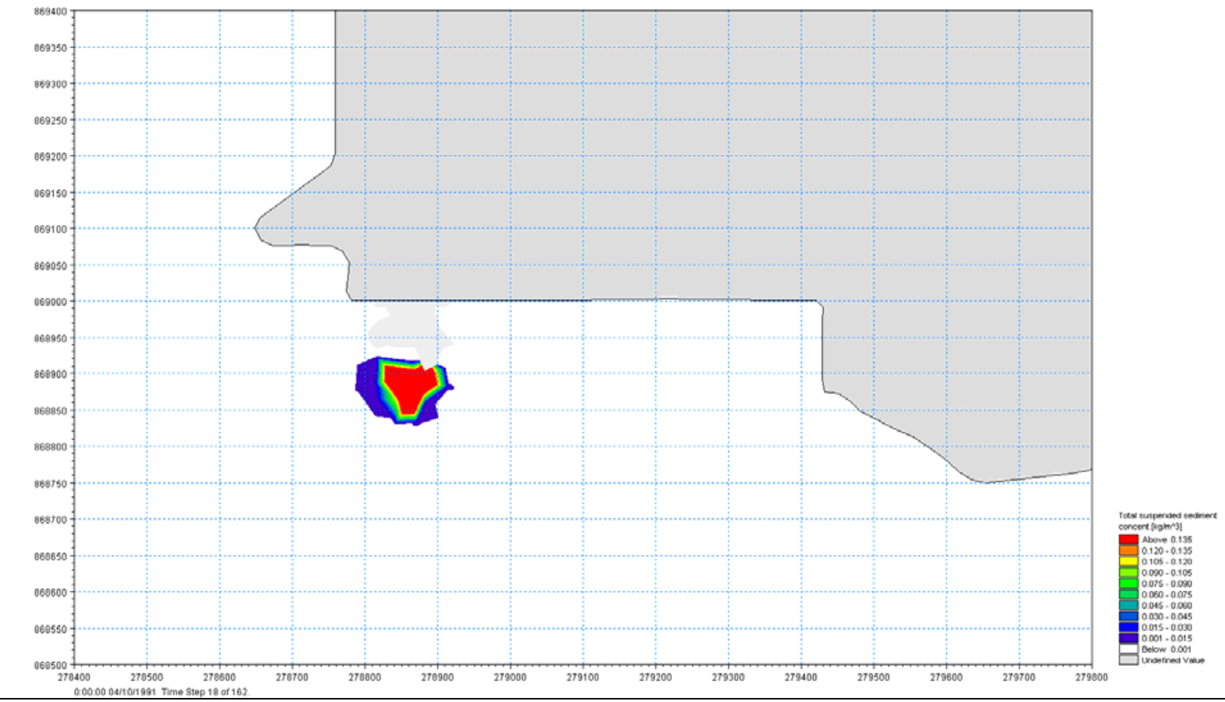
15 hours after start of release



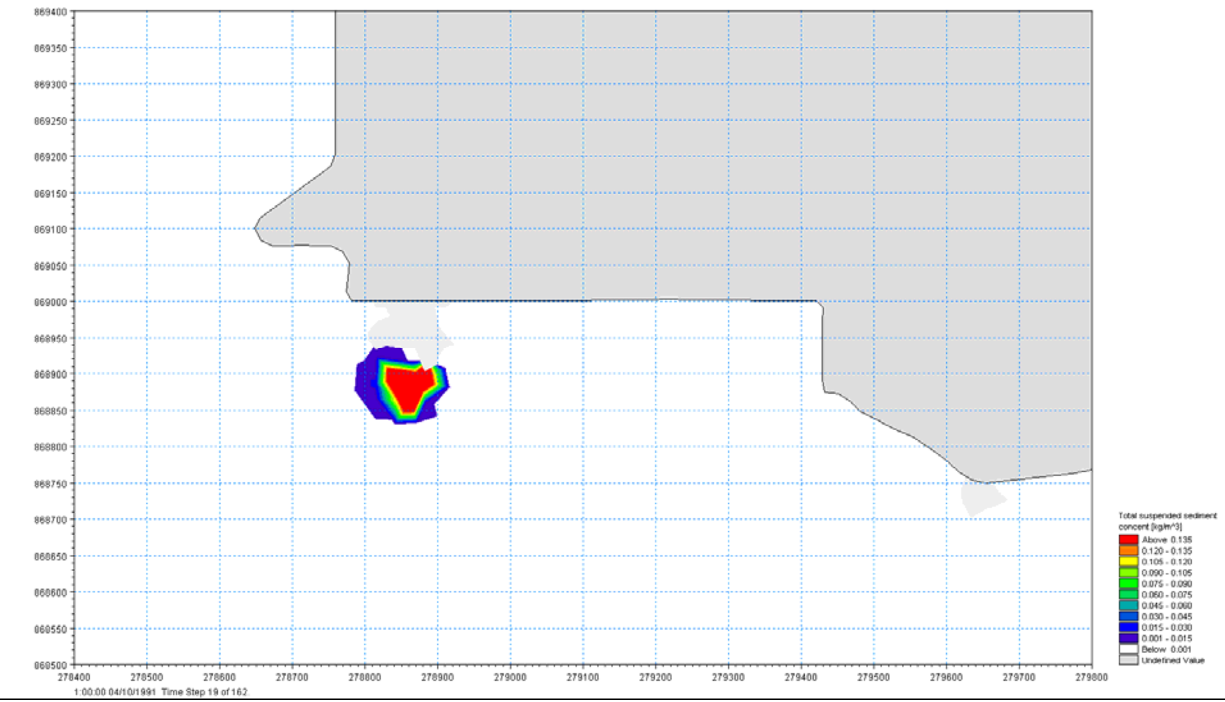
16 hours after start of release



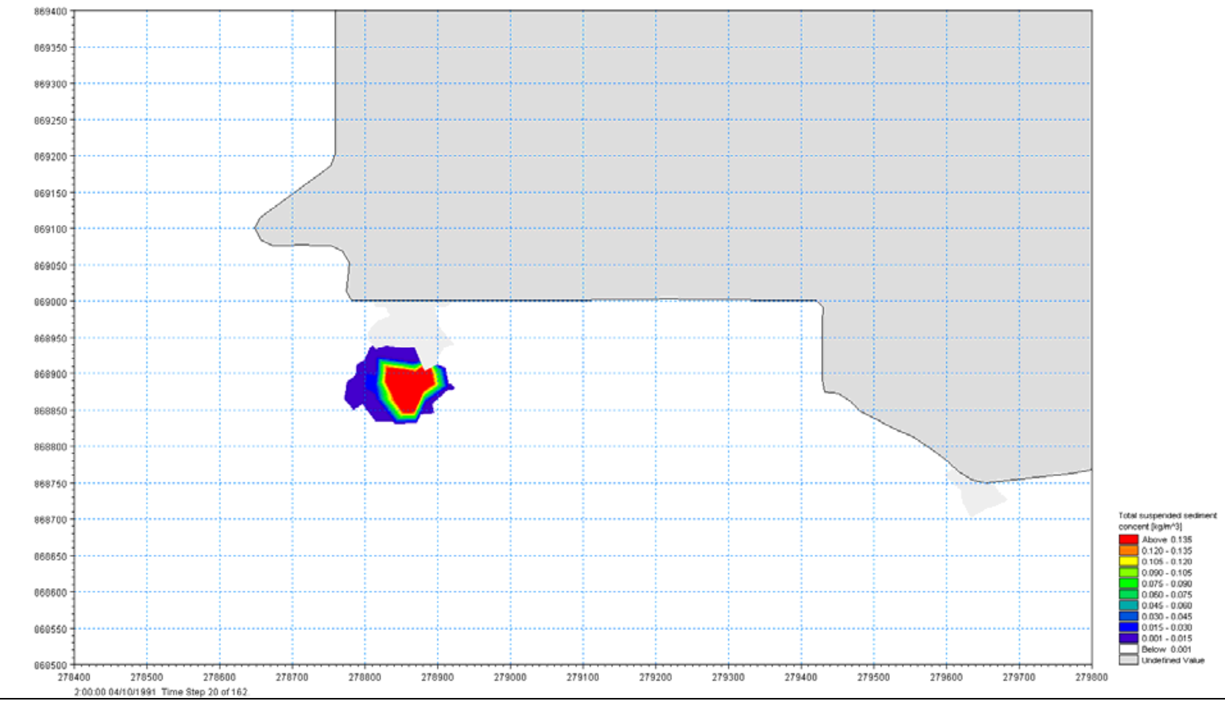
17 hours after start of release



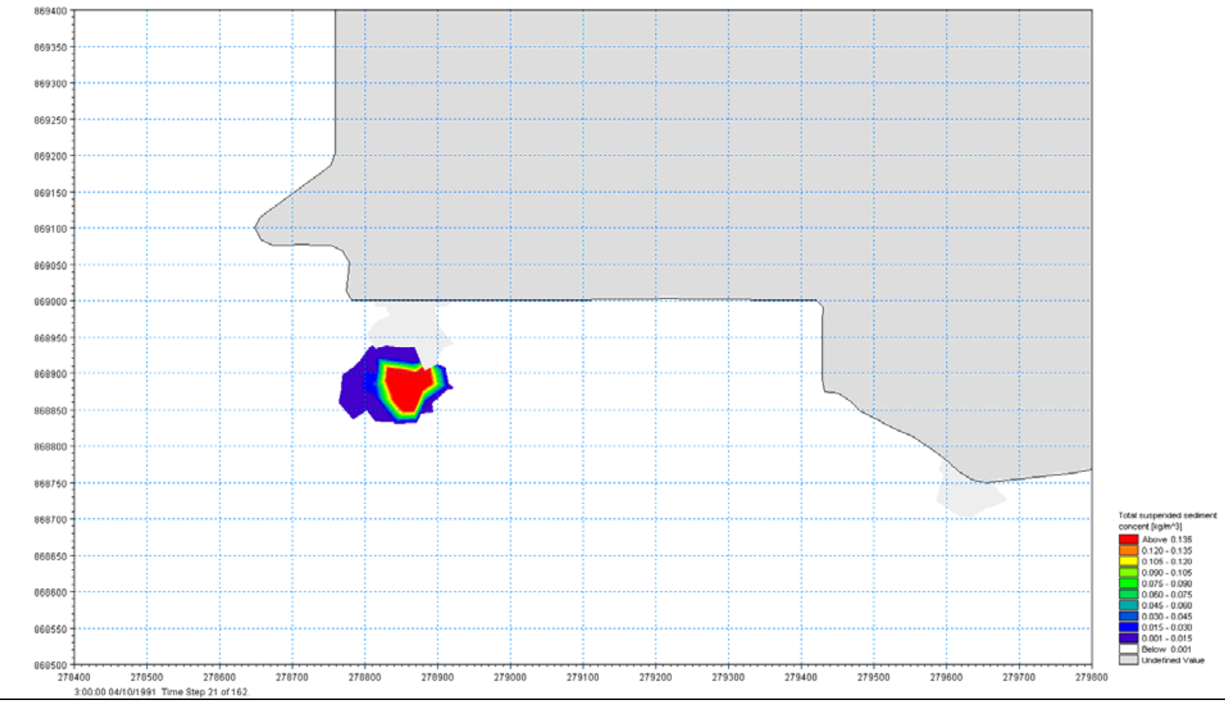
18 hours after start of release



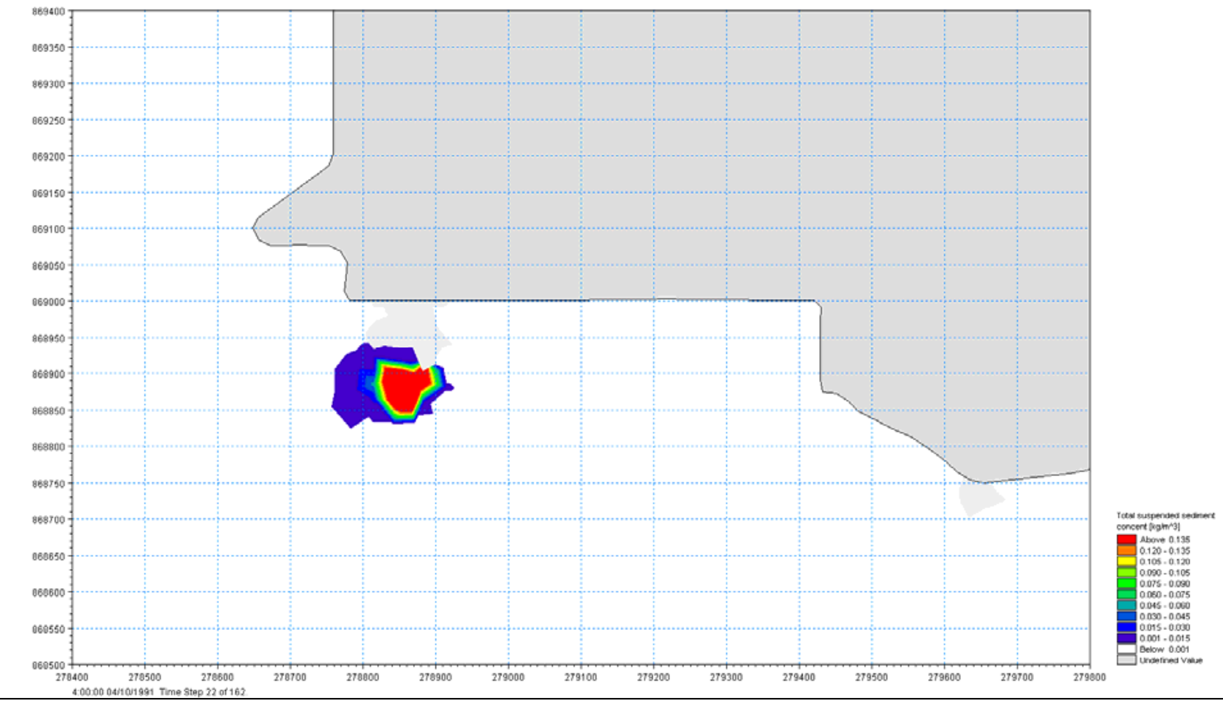
19 hours after start of release



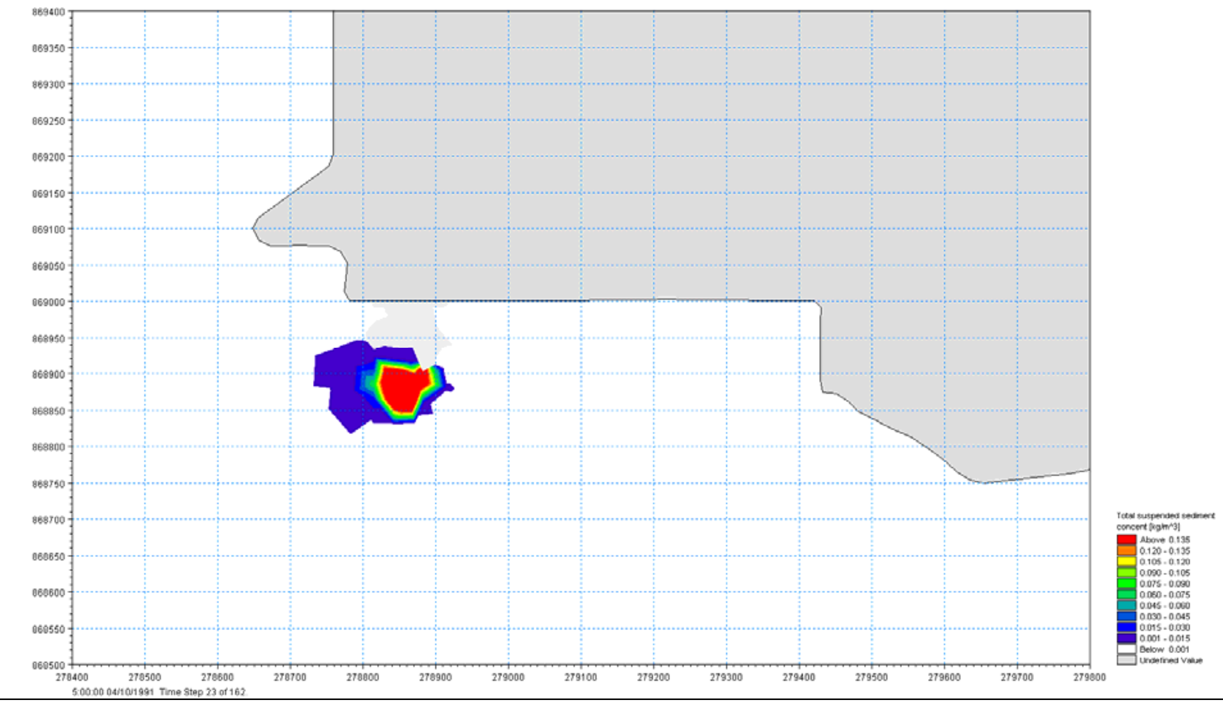
20 hours after start of release



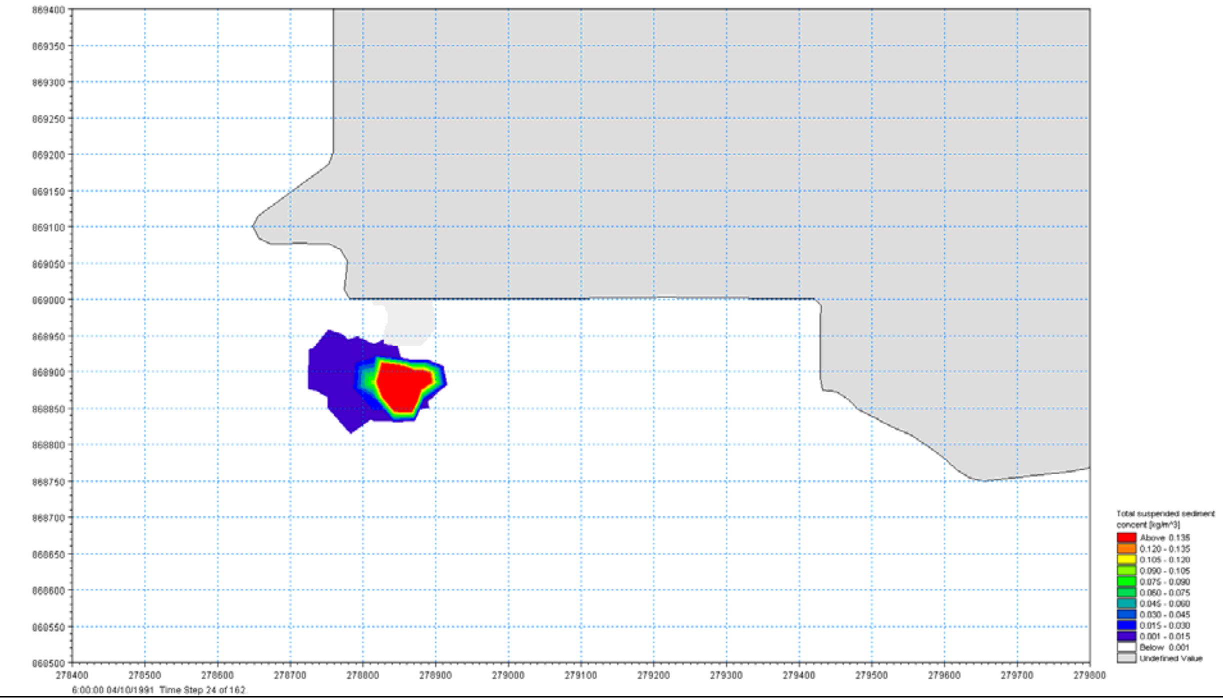
21 hours after start of release



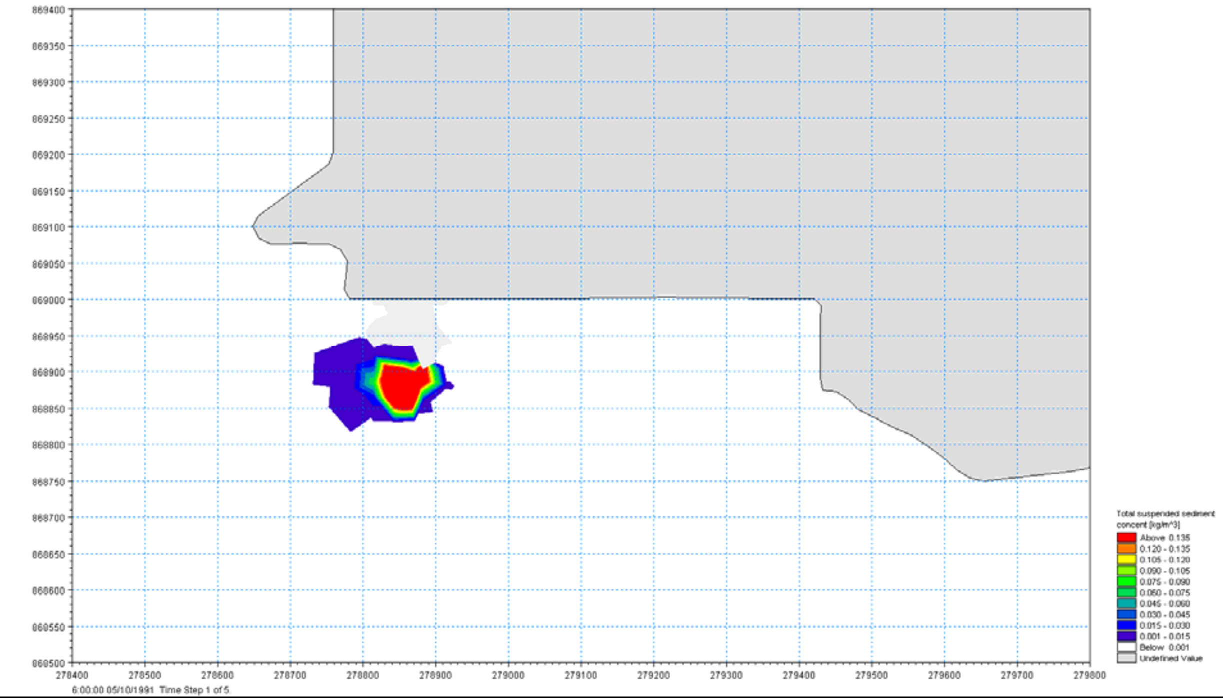
22 hours after start of release



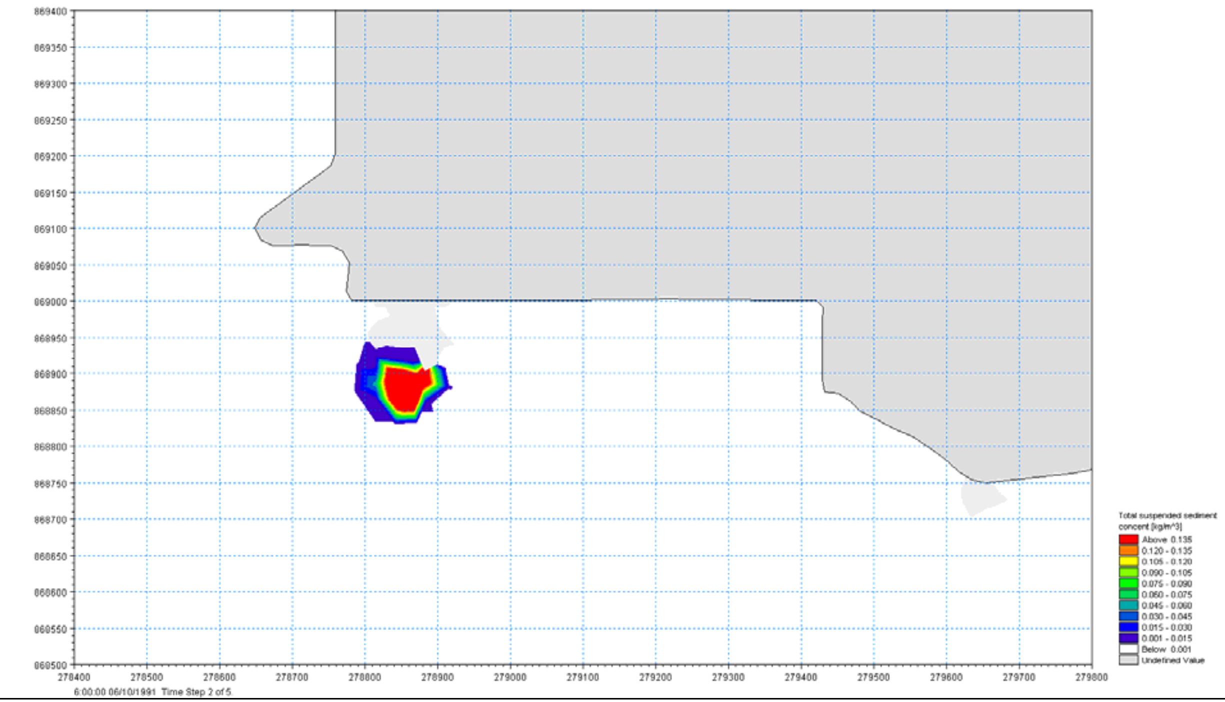
23 hours after start of release



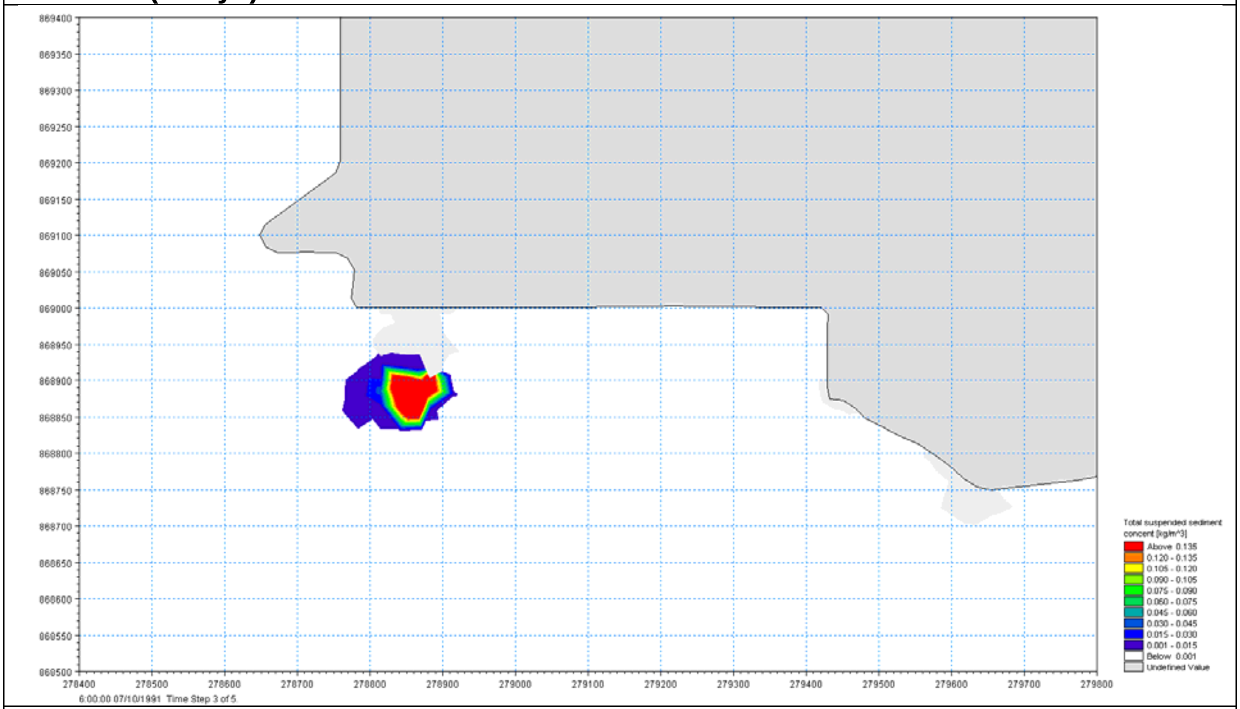
24 hours (1 day) after start of release



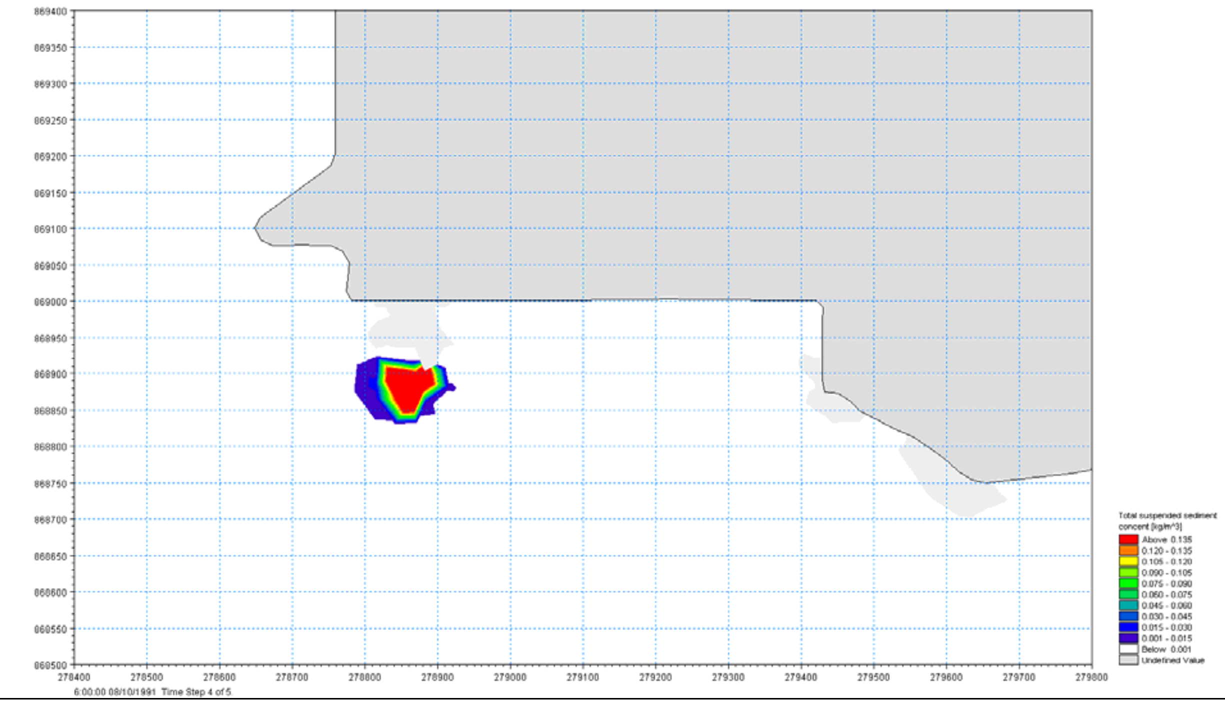
48 hours (2 days) after start of release



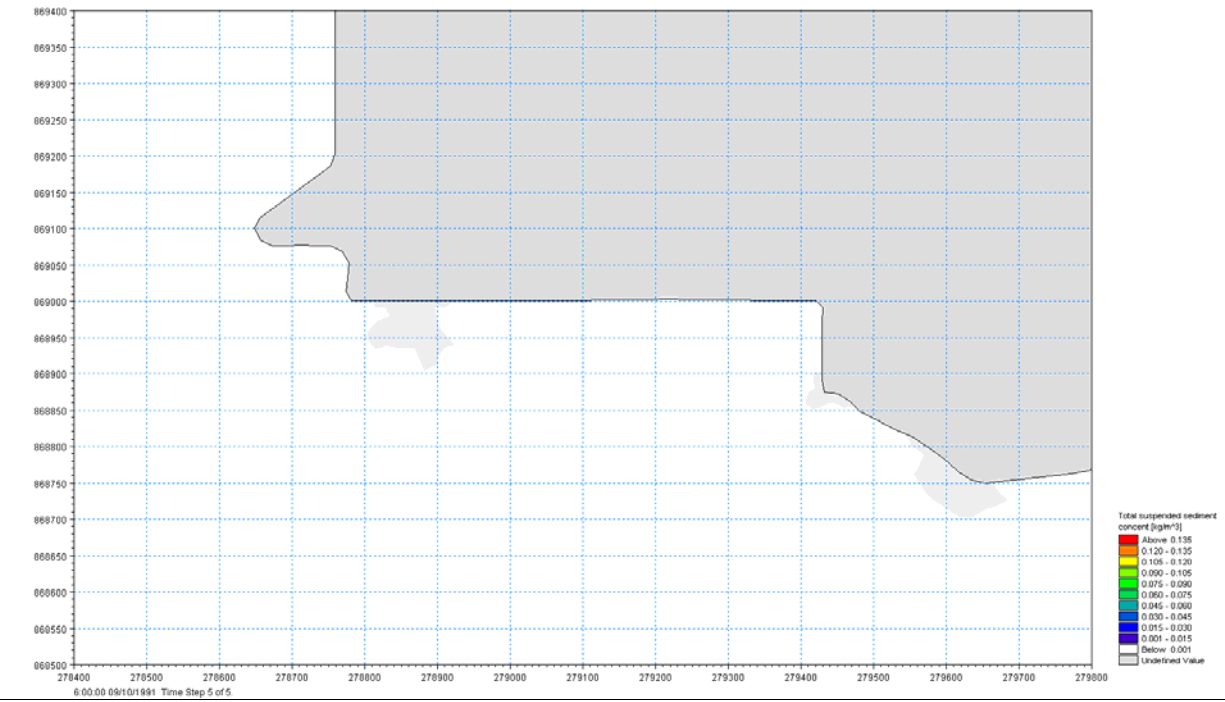
72 hours (3 days) after start of release



96 hours (4 days) after start of release



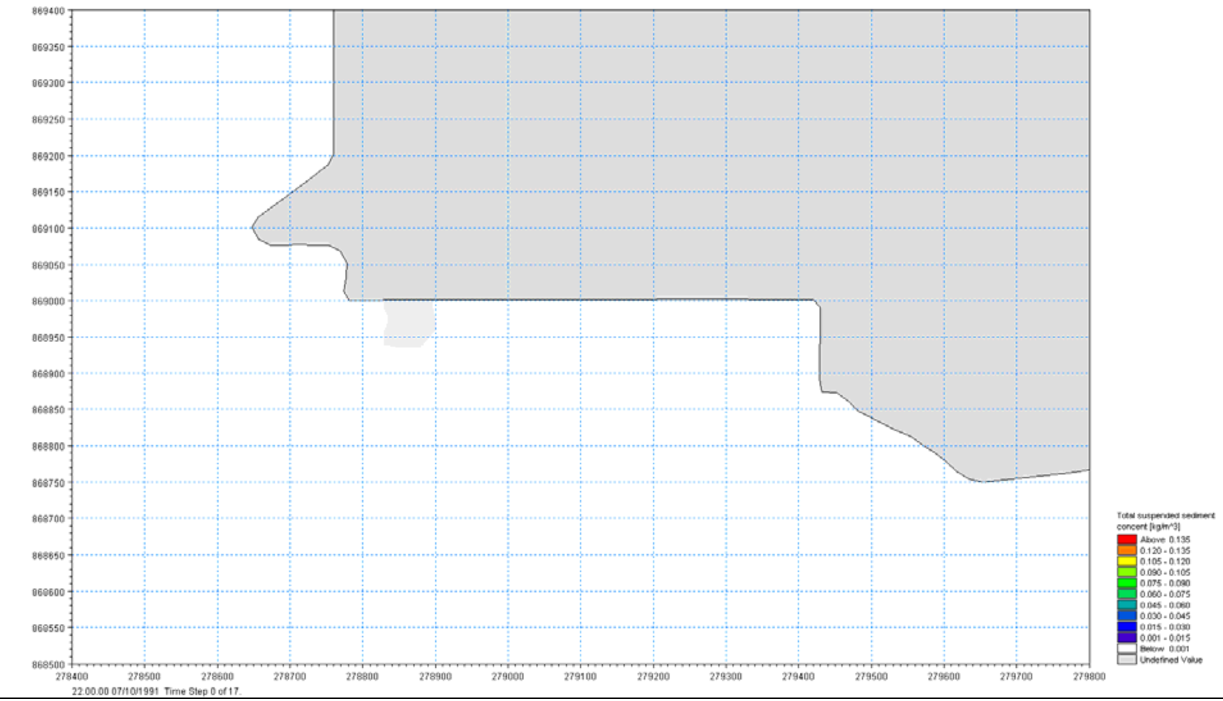
120 hours (5 days) after start of release



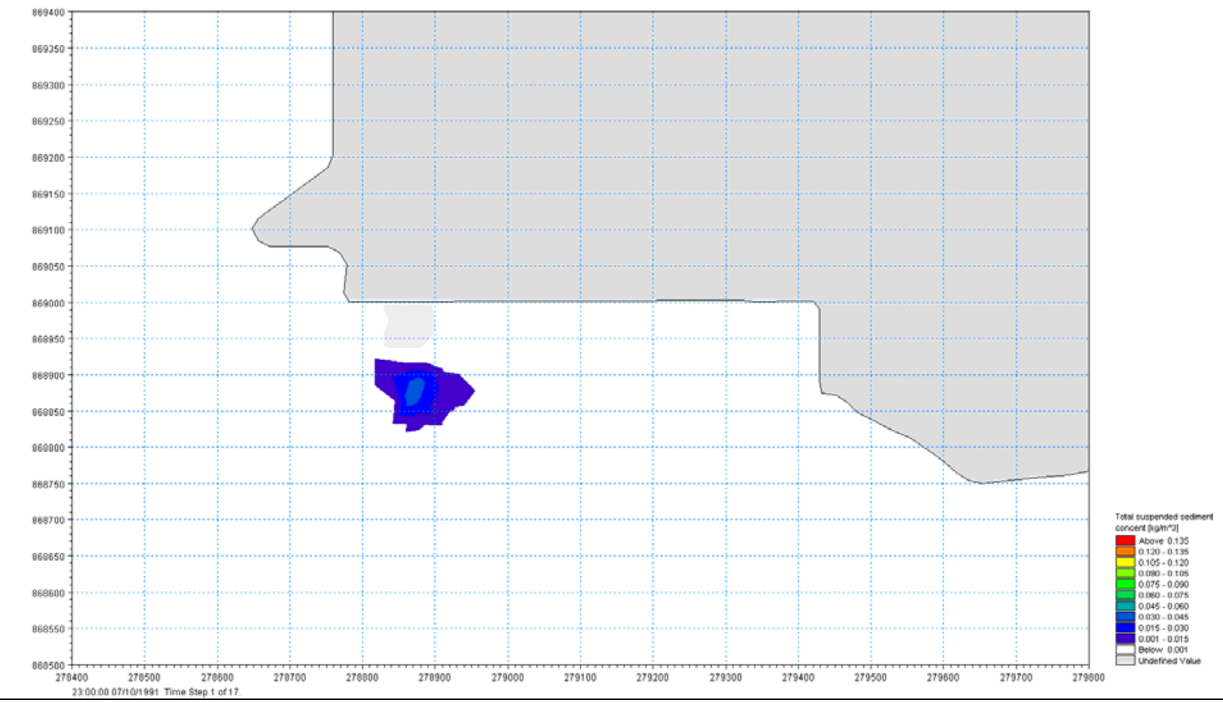
144 hours (6 days) after start of release

APPENDIX C

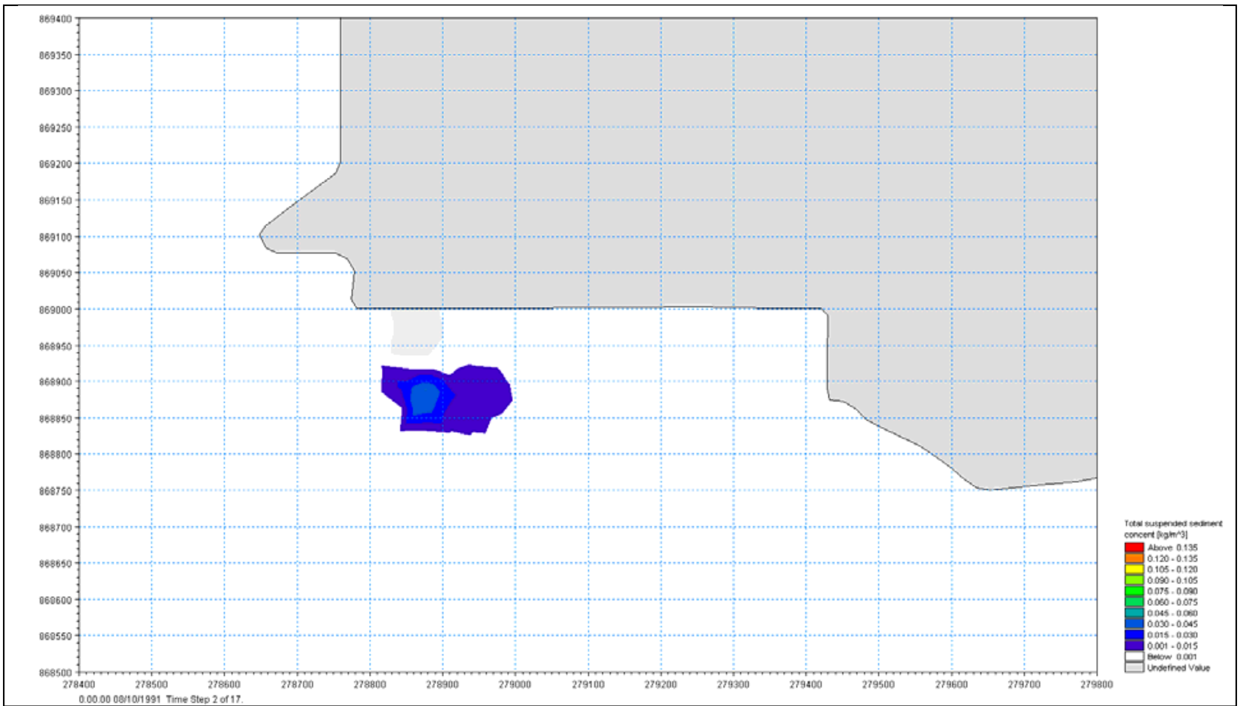
SCENARIO 3 MODELLING RESULTS



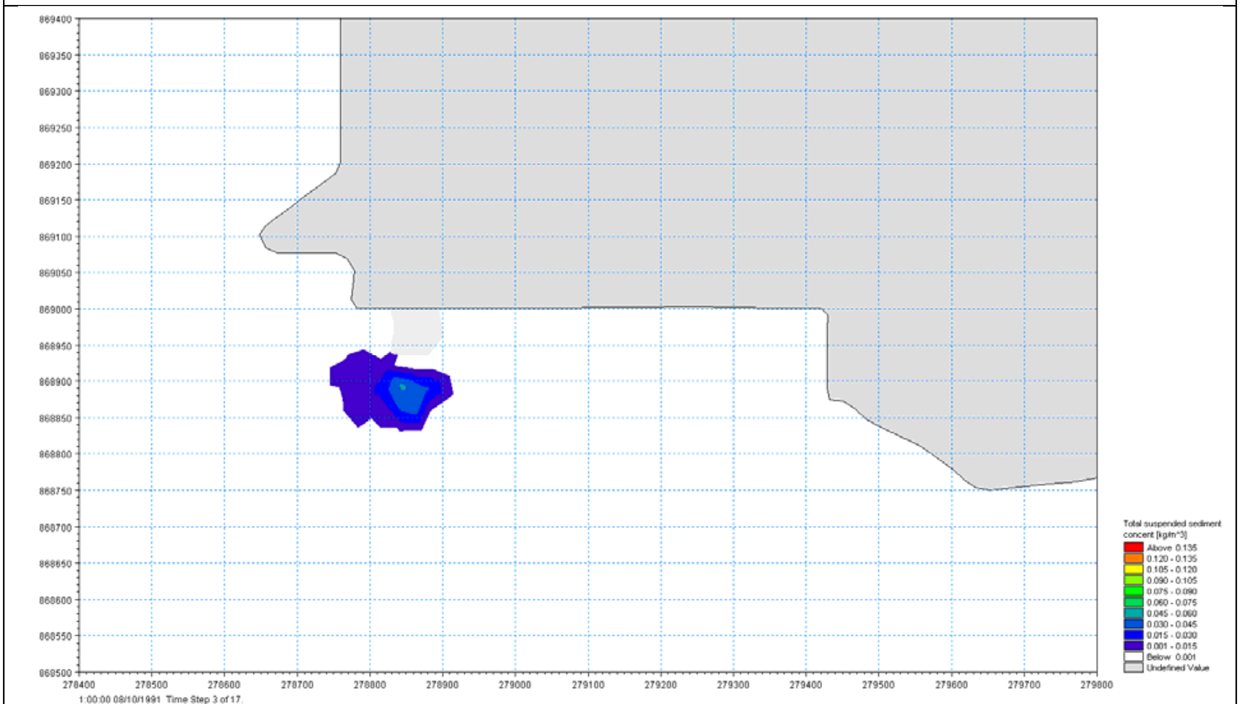
0 hours after start of release



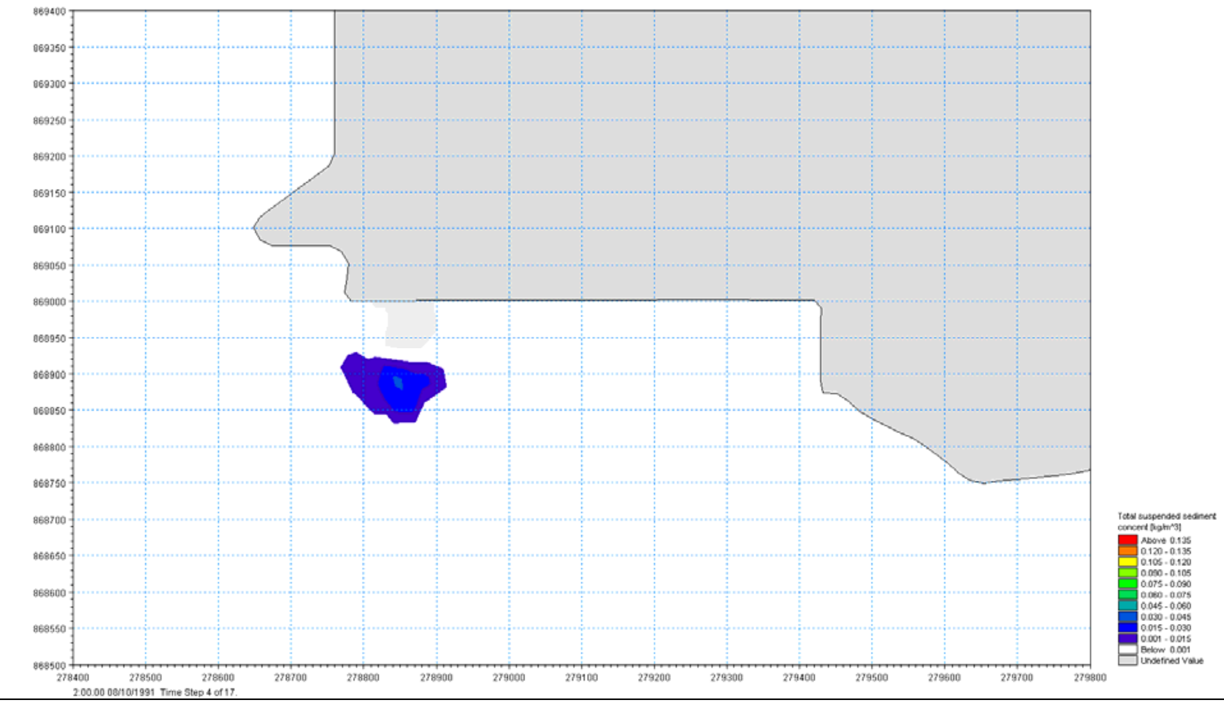
1 hour after start of release



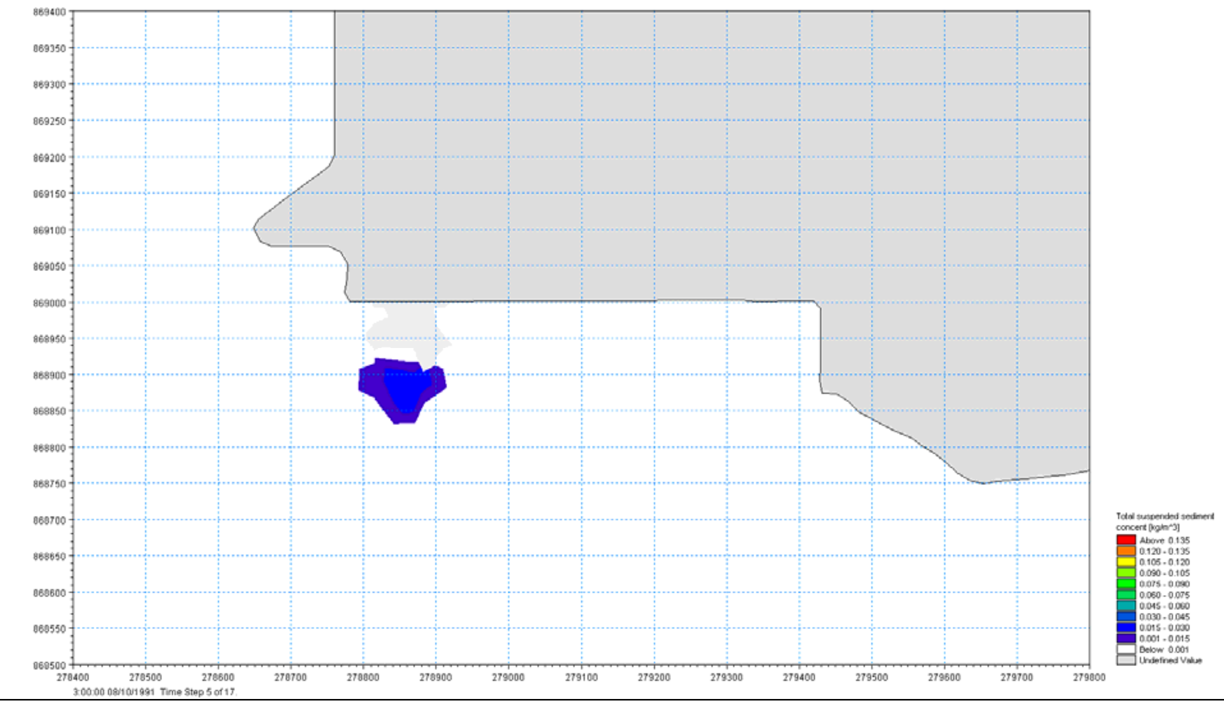
2 hours after start of release



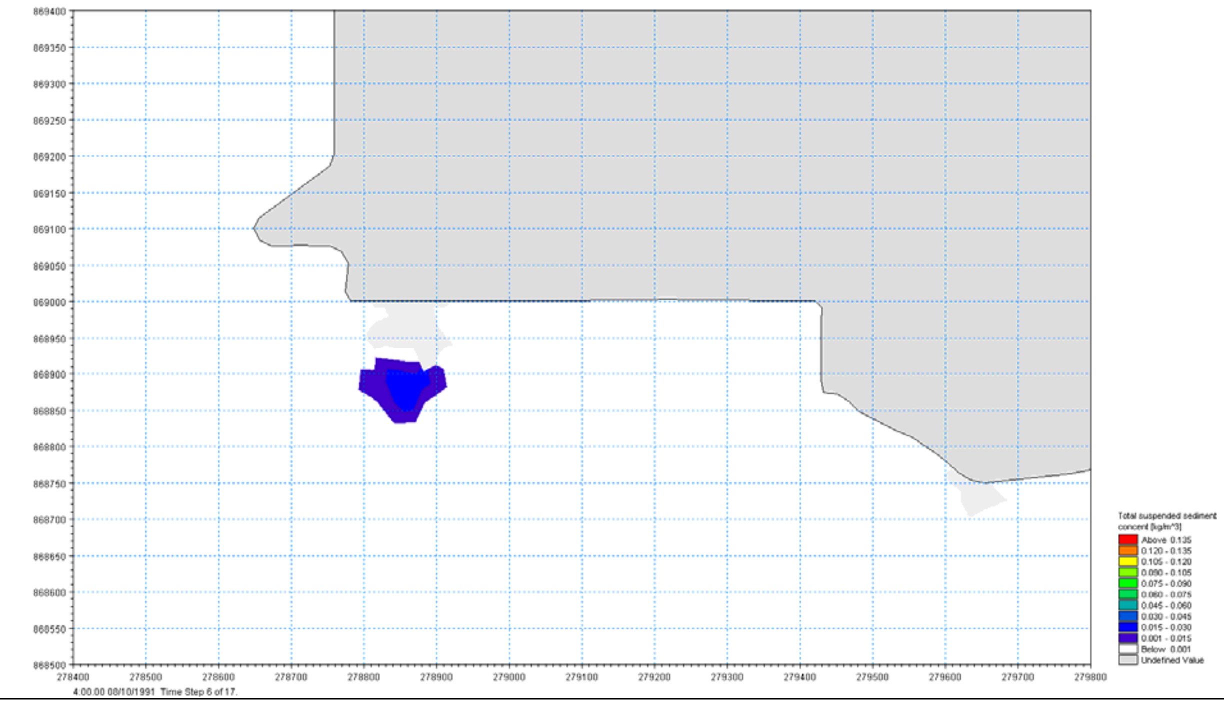
3 hours after start of release



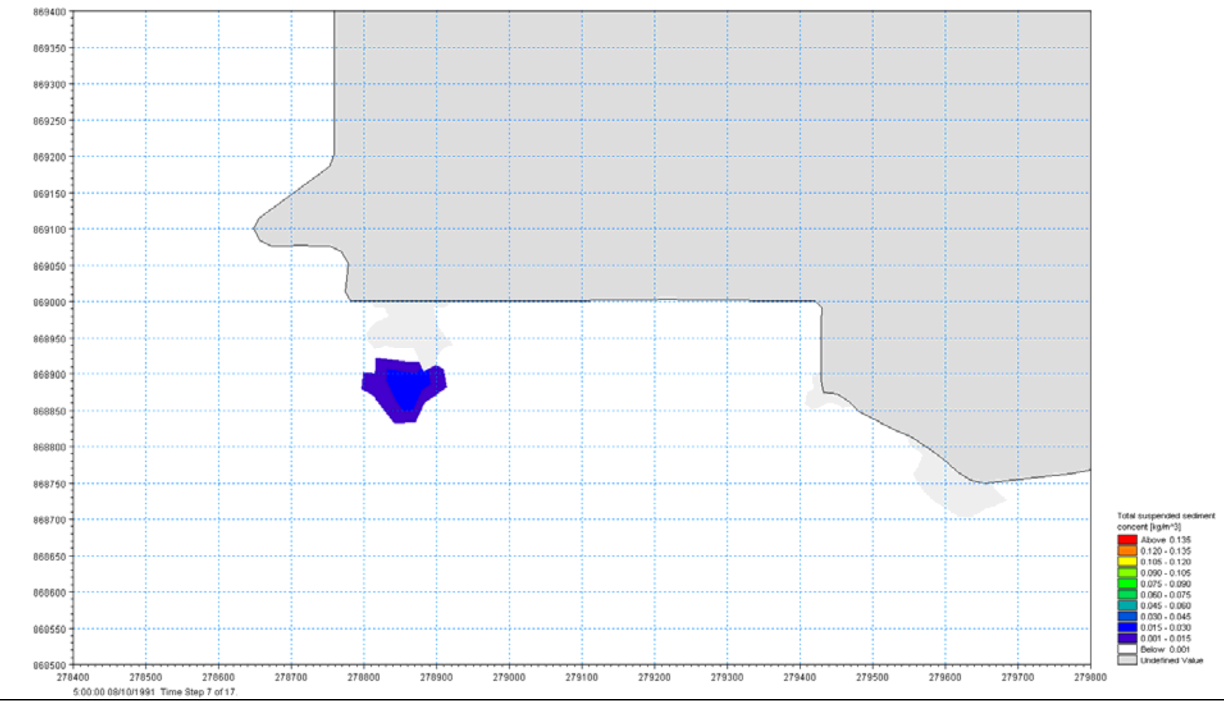
4 hours after start of release



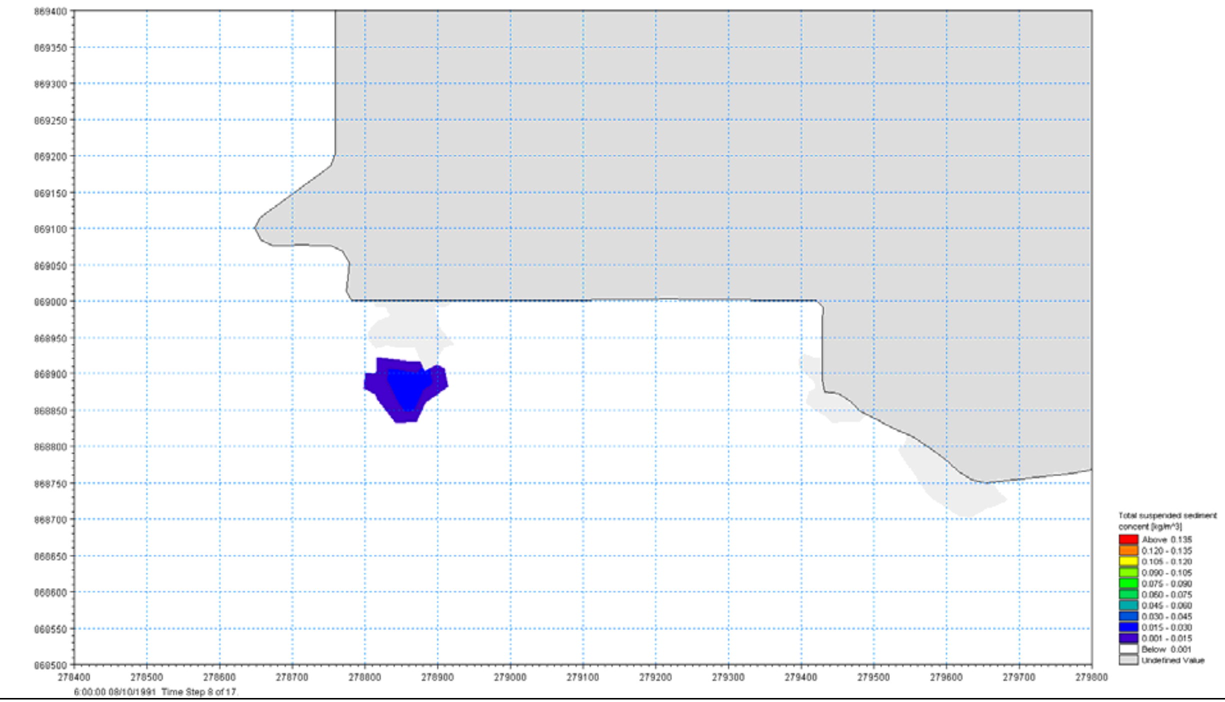
5 hours after start of release



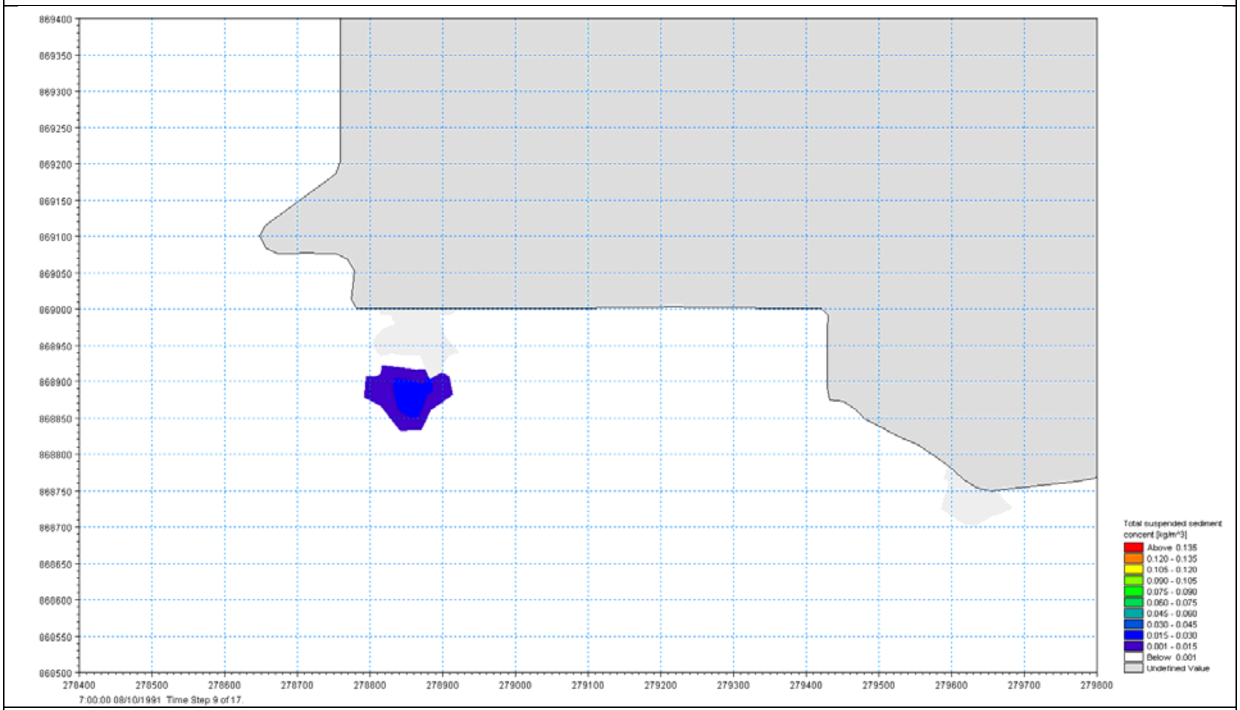
6 hours after start of release



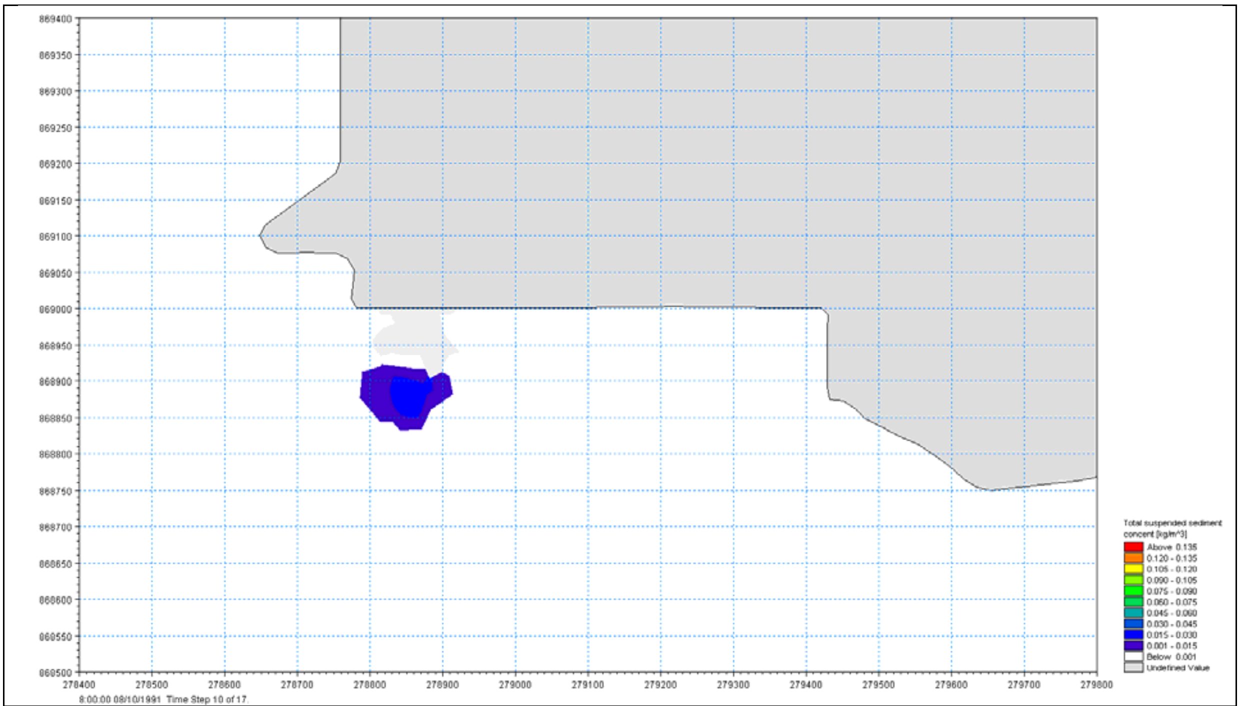
7 hours after start of release



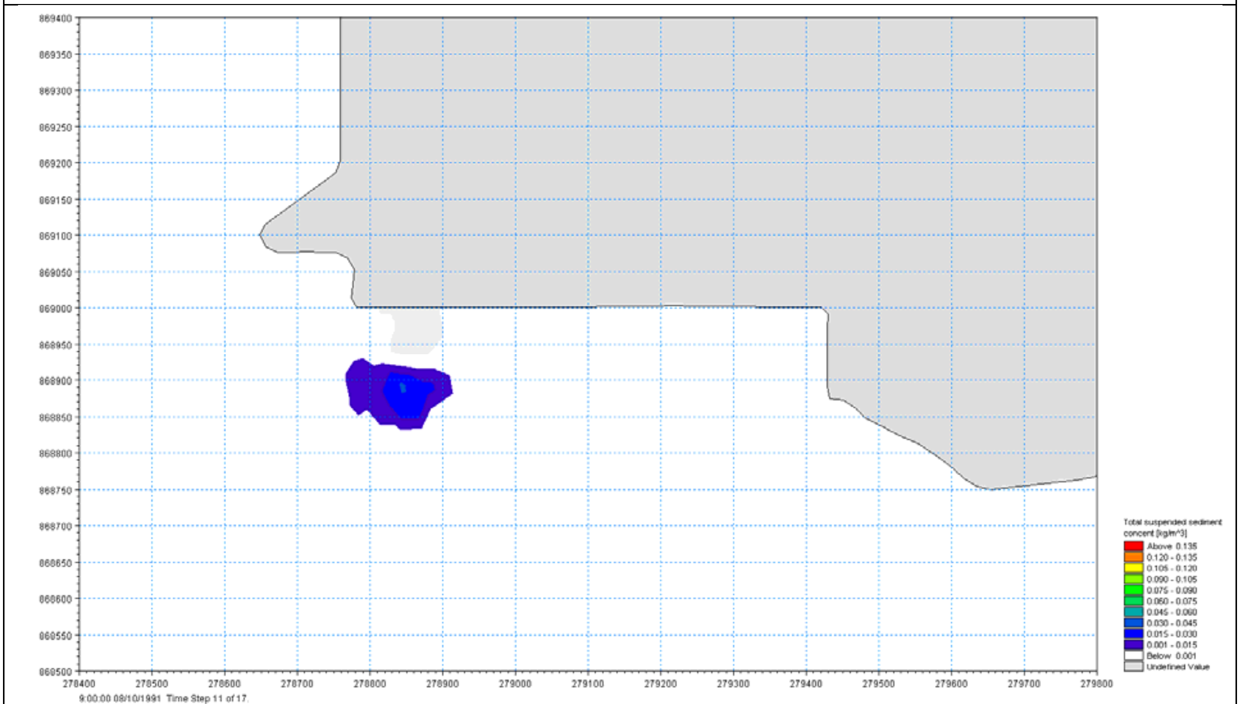
8 hours after start of release



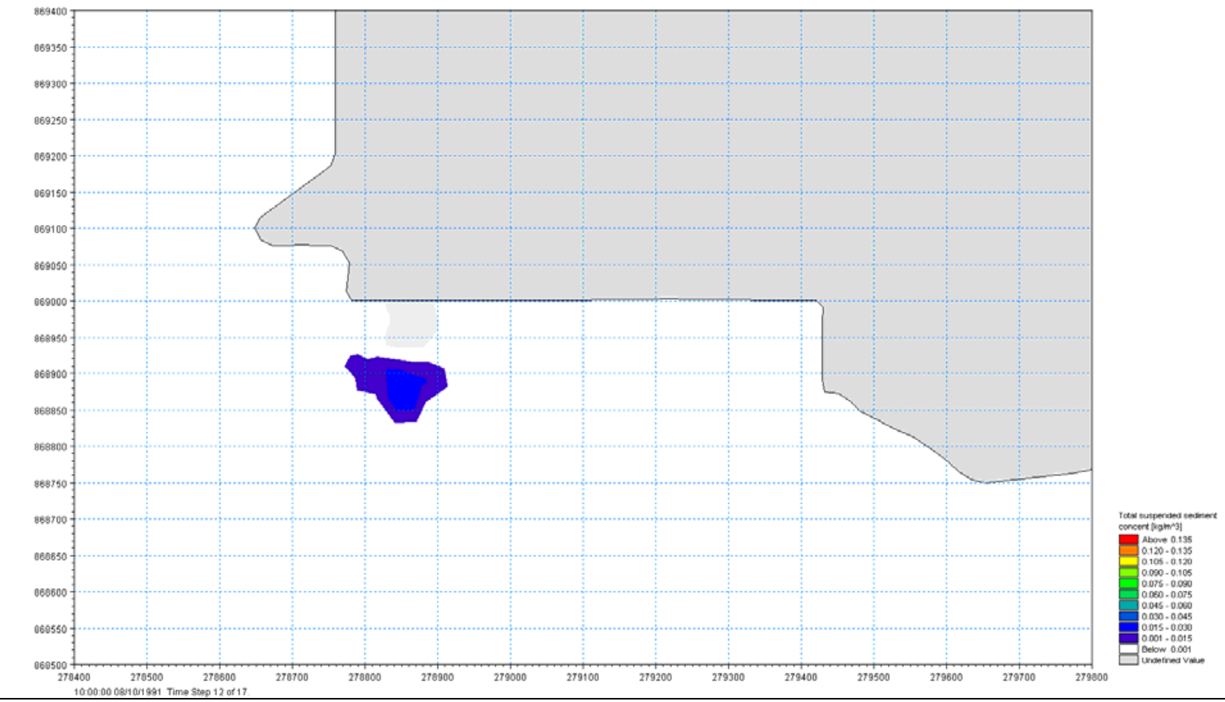
9 hours after start of release



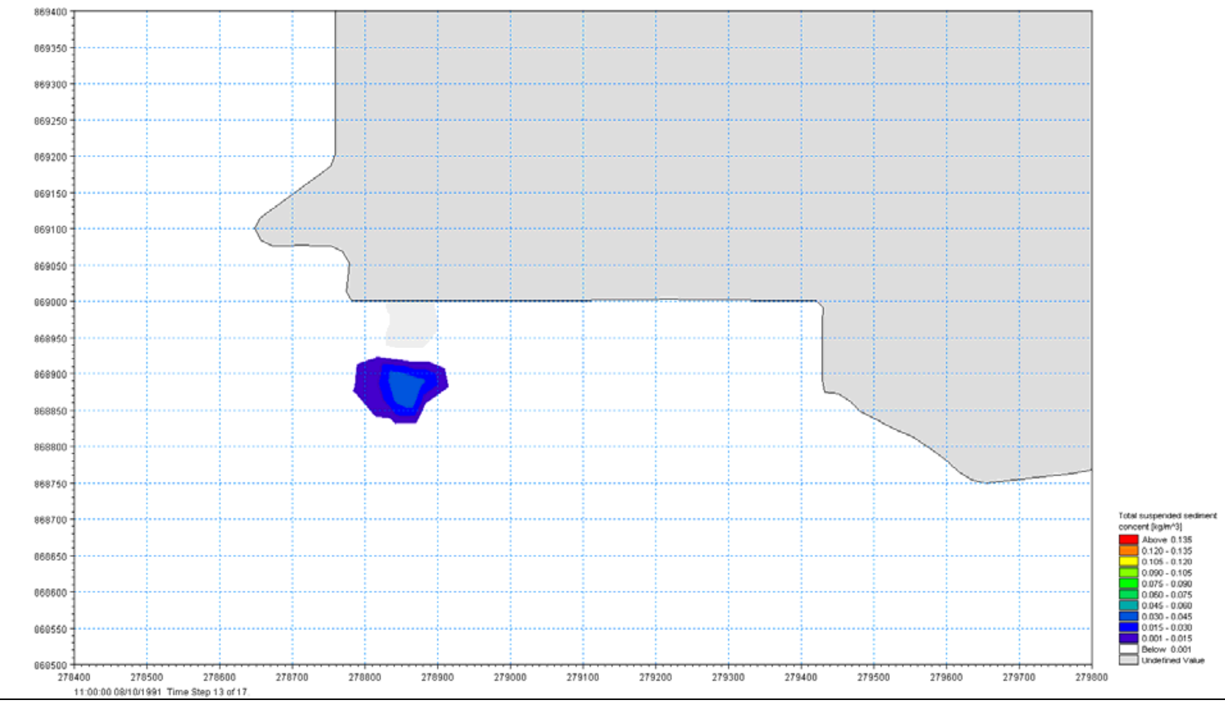
10 hours after start of release



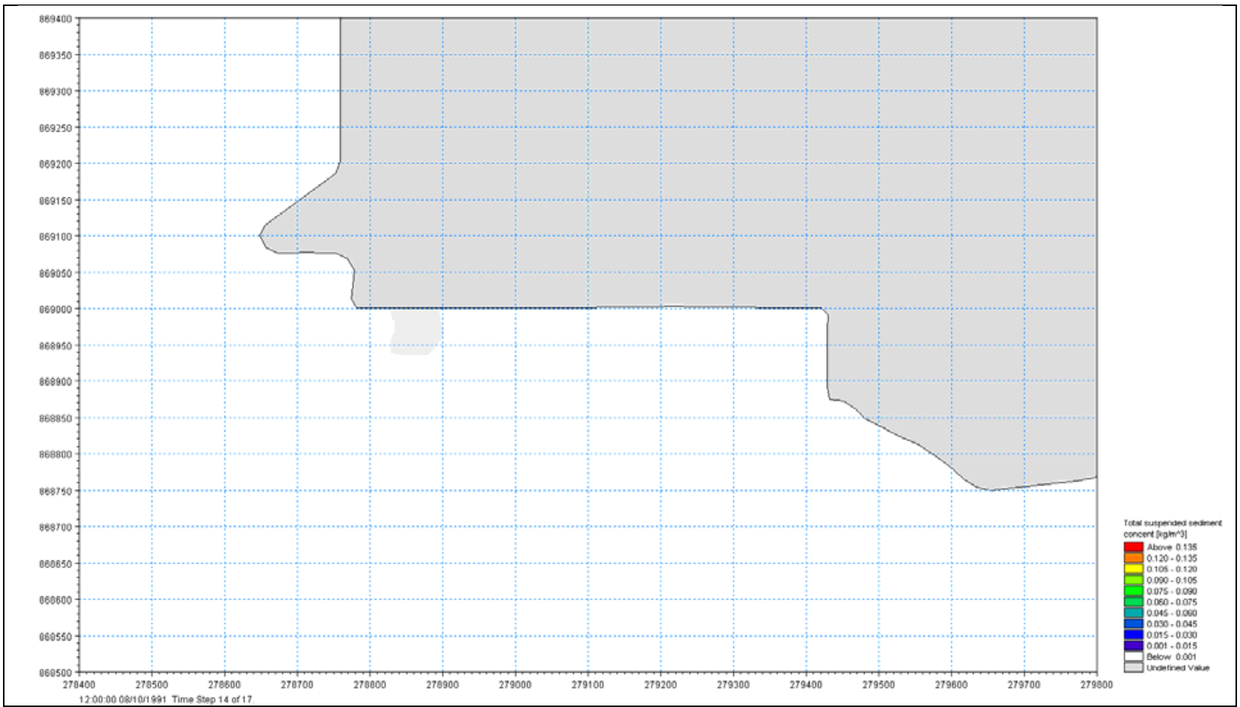
11 hours after start of release



12 hours after start of release



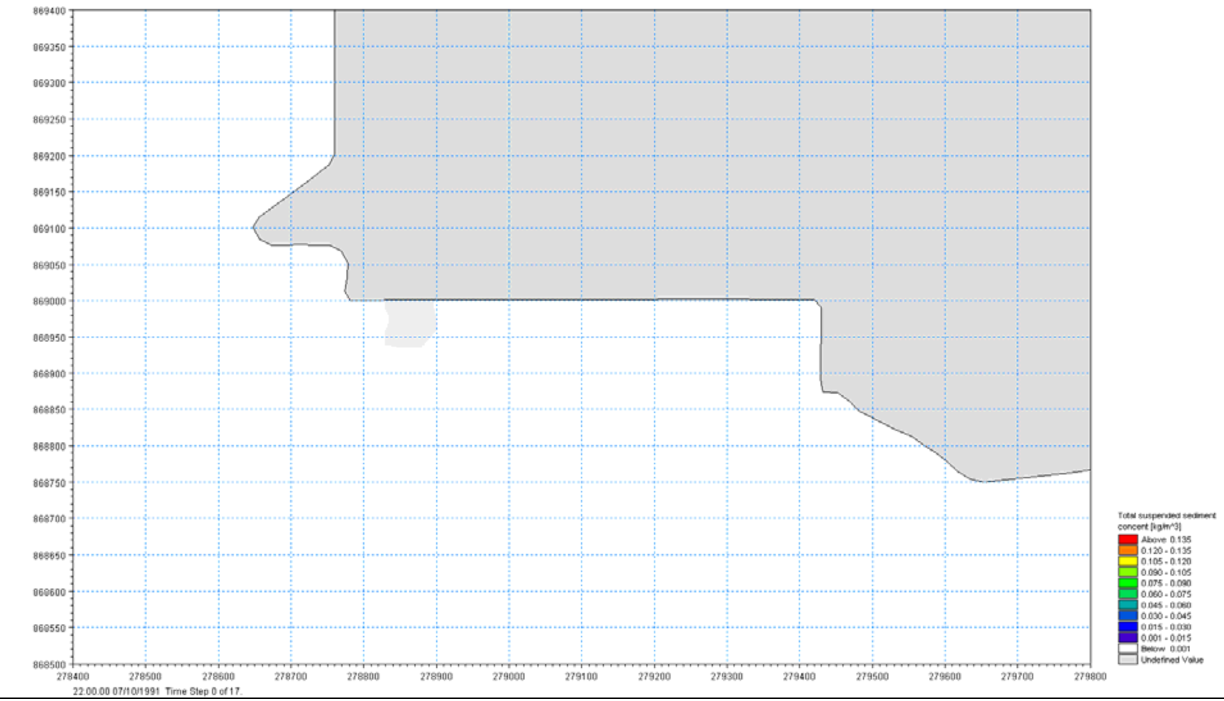
13 hours after start of release



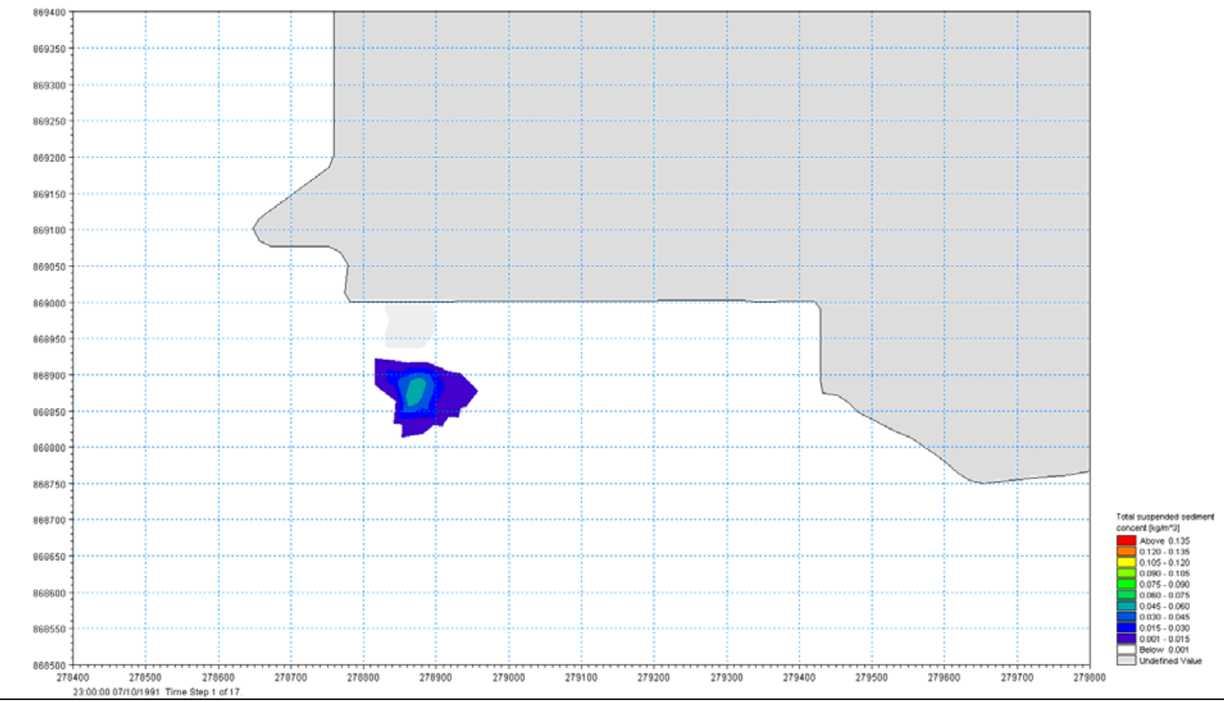
14 hours after start of release

APPENDIX D

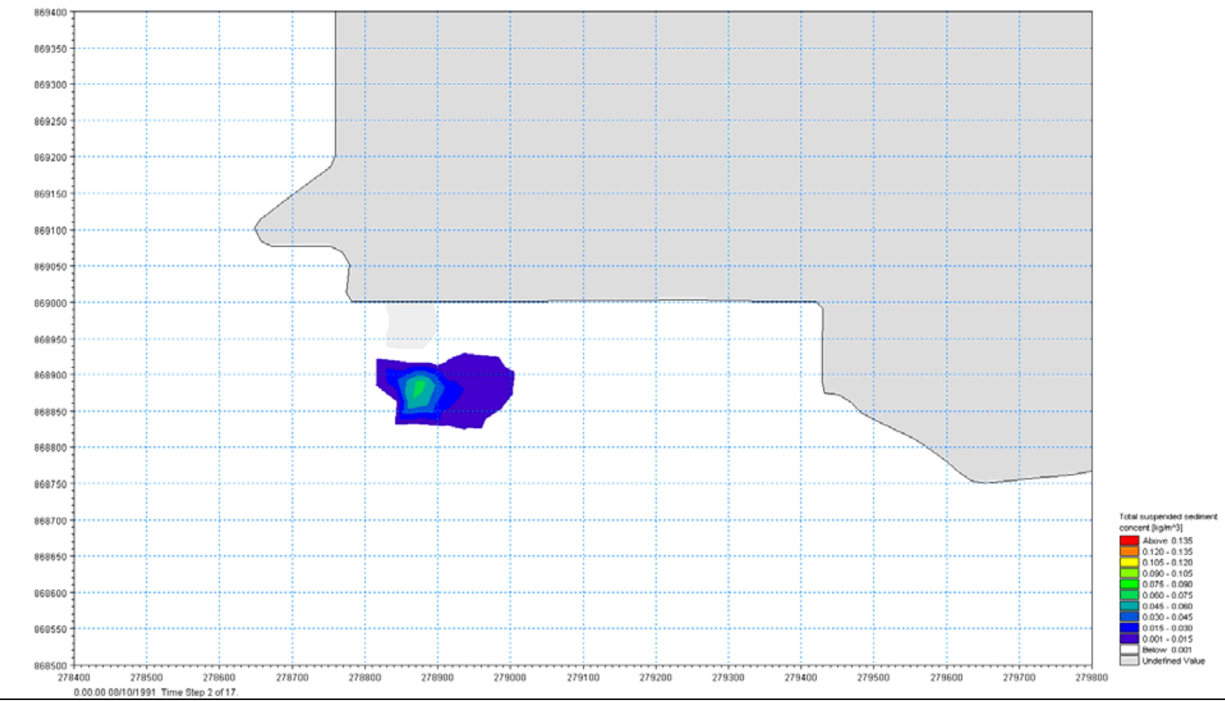
SCENARIO 4 MODELLING RESULTS



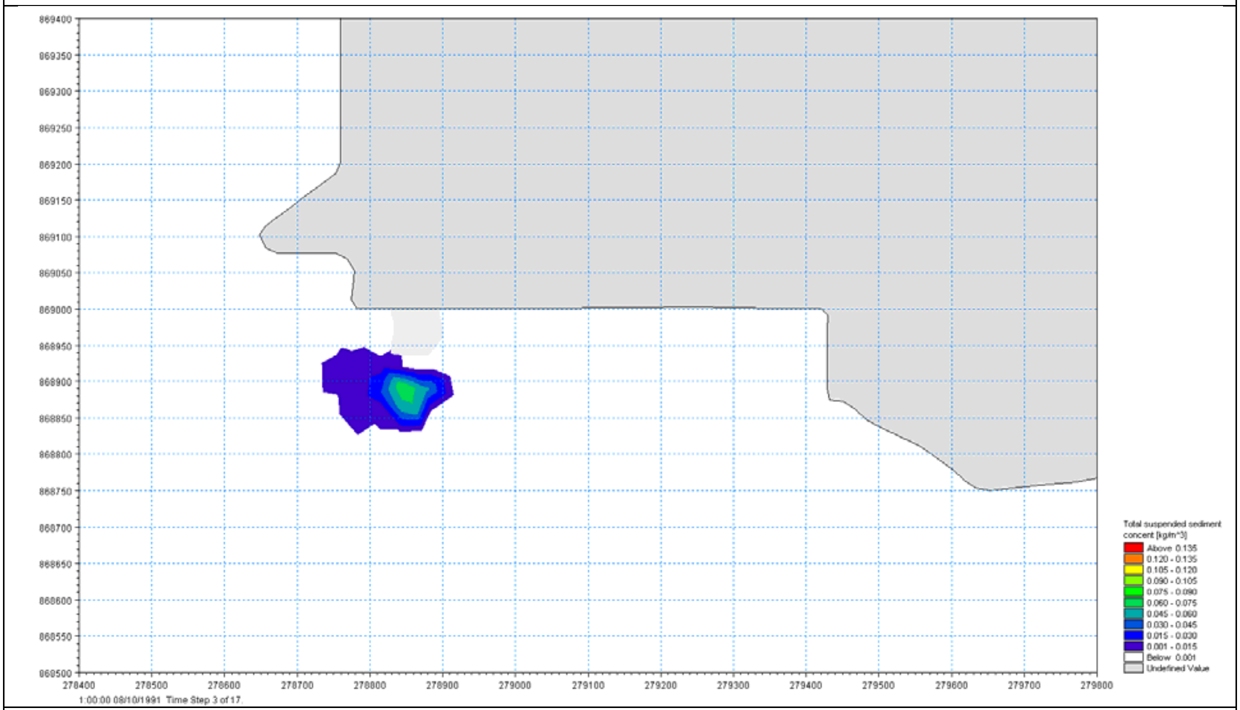
0 hours after start of release



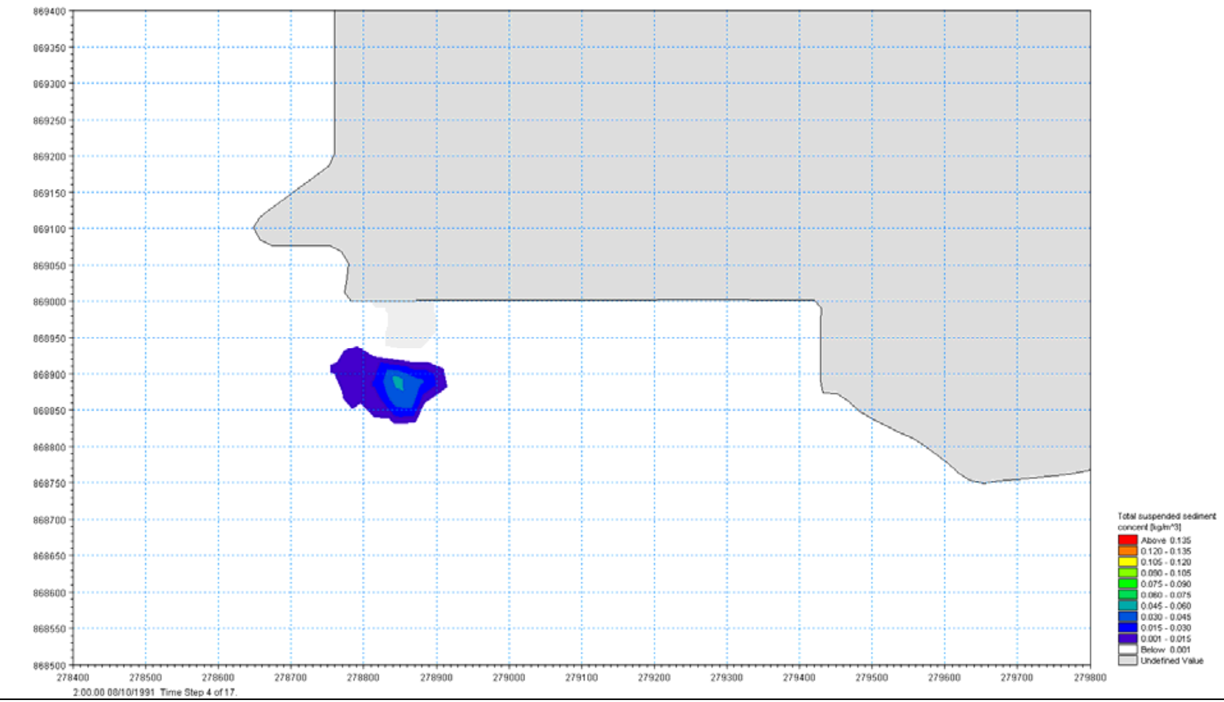
1 hour after start of release



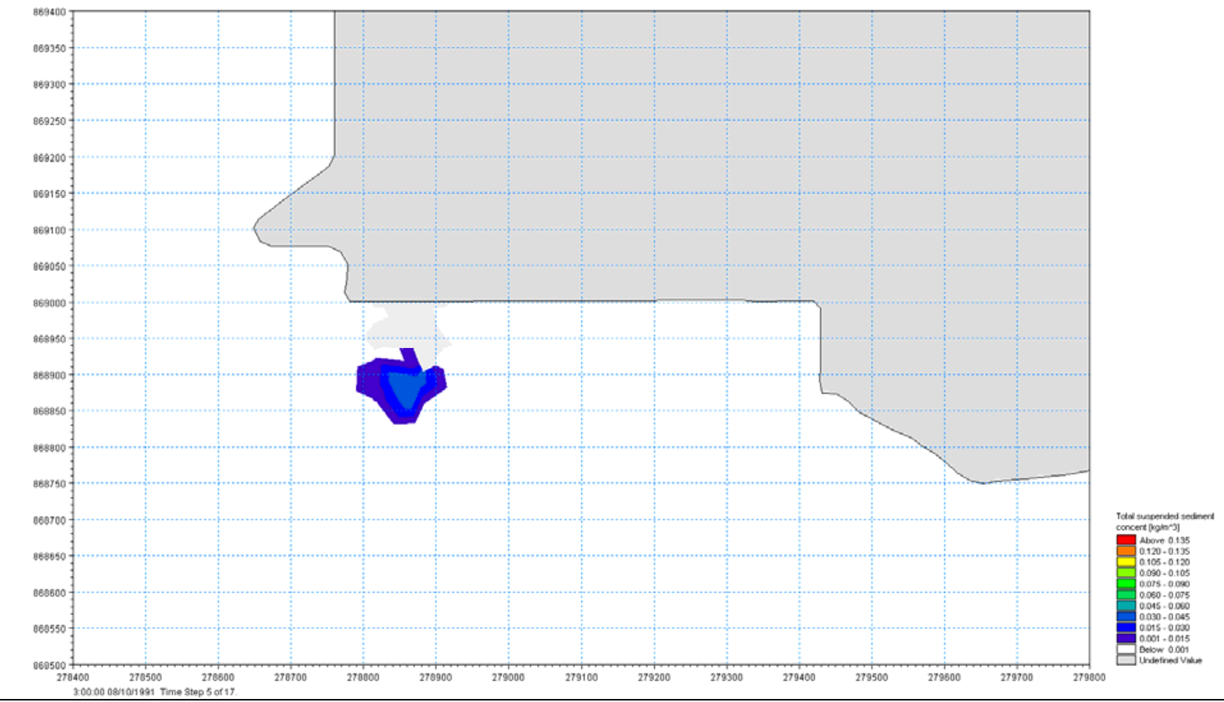
2 hours after start of release



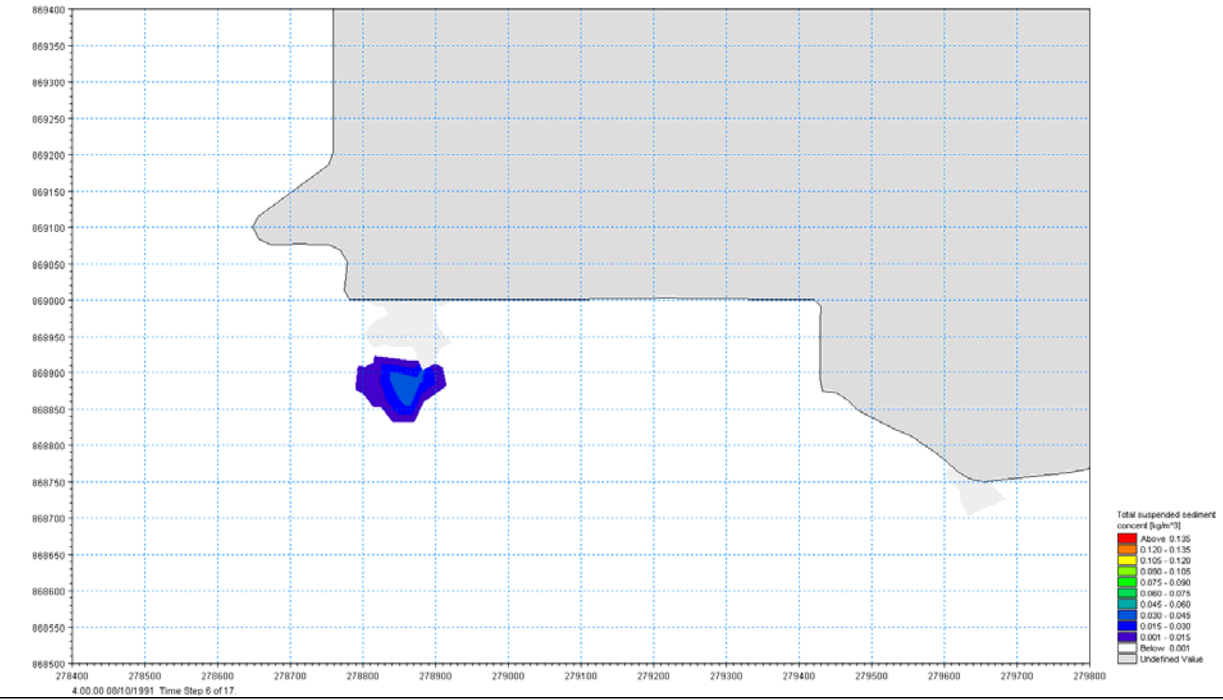
3 hours after start of release



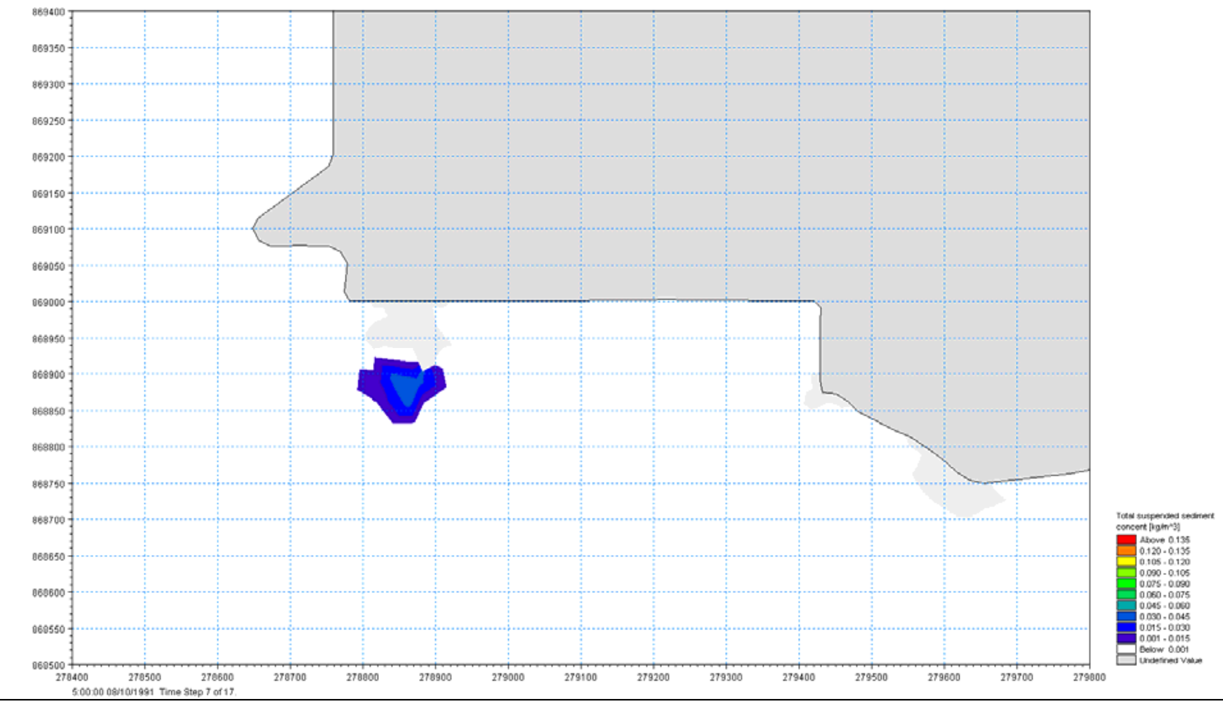
4 hours after start of release



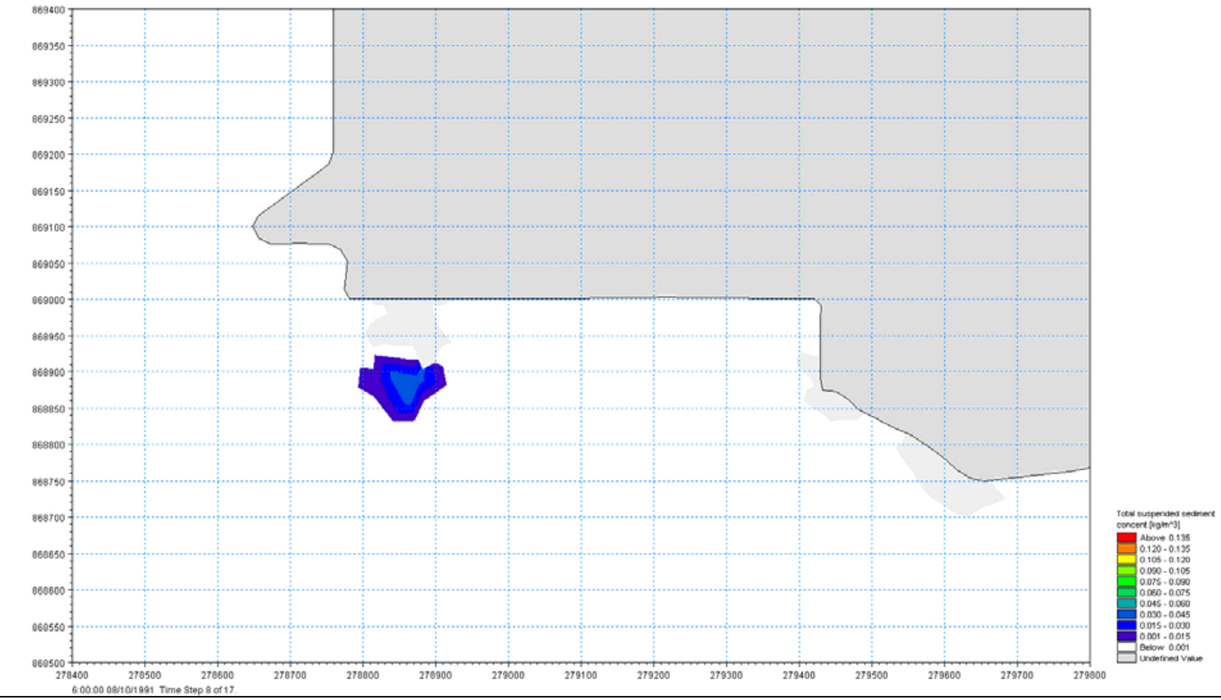
5 hours after start of release



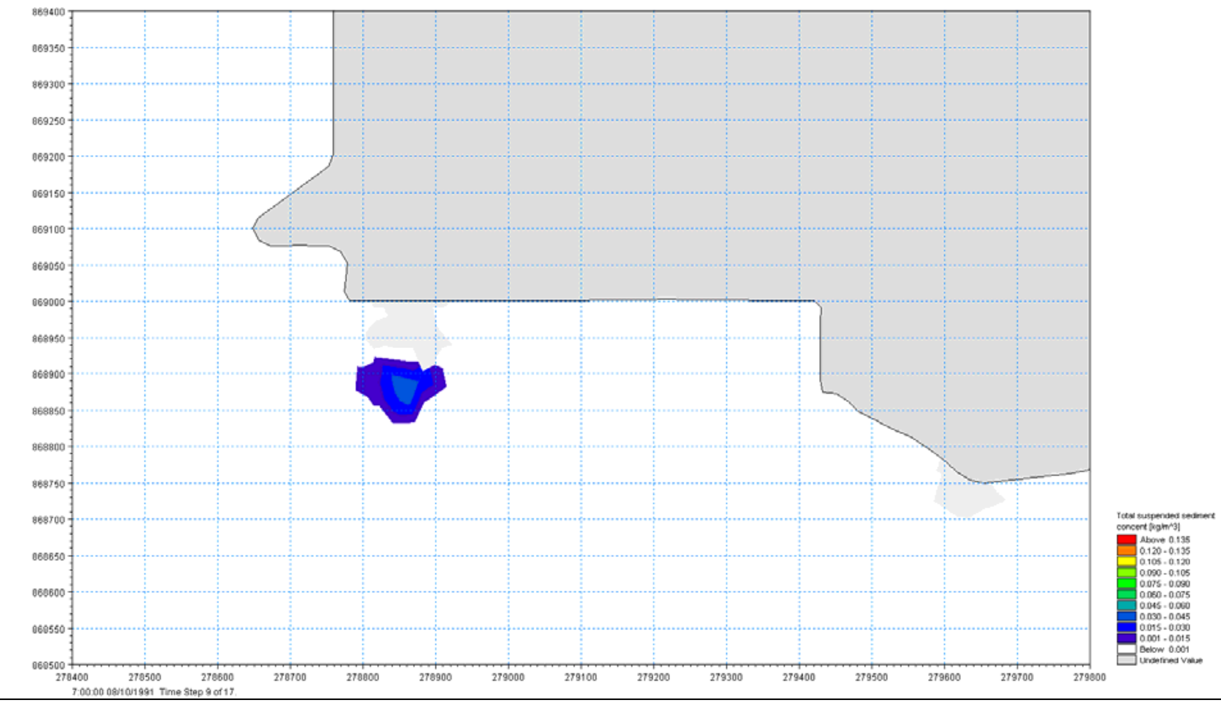
6 hours after start of release



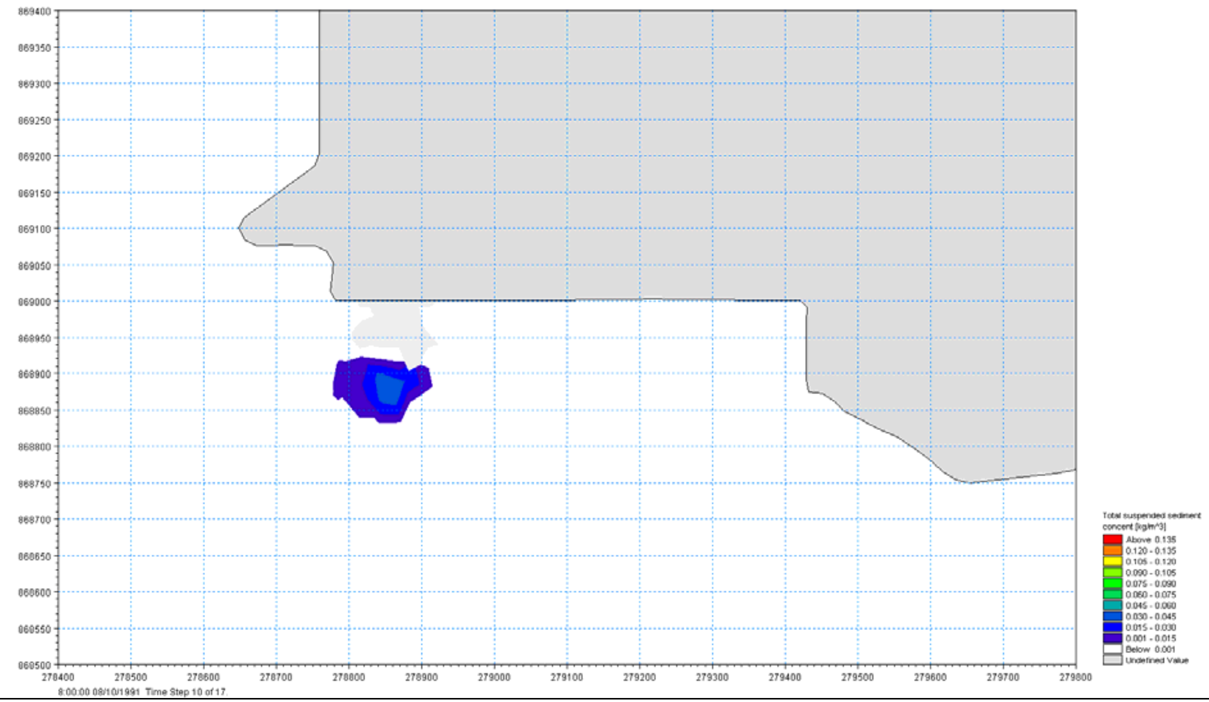
7 hours after start of release



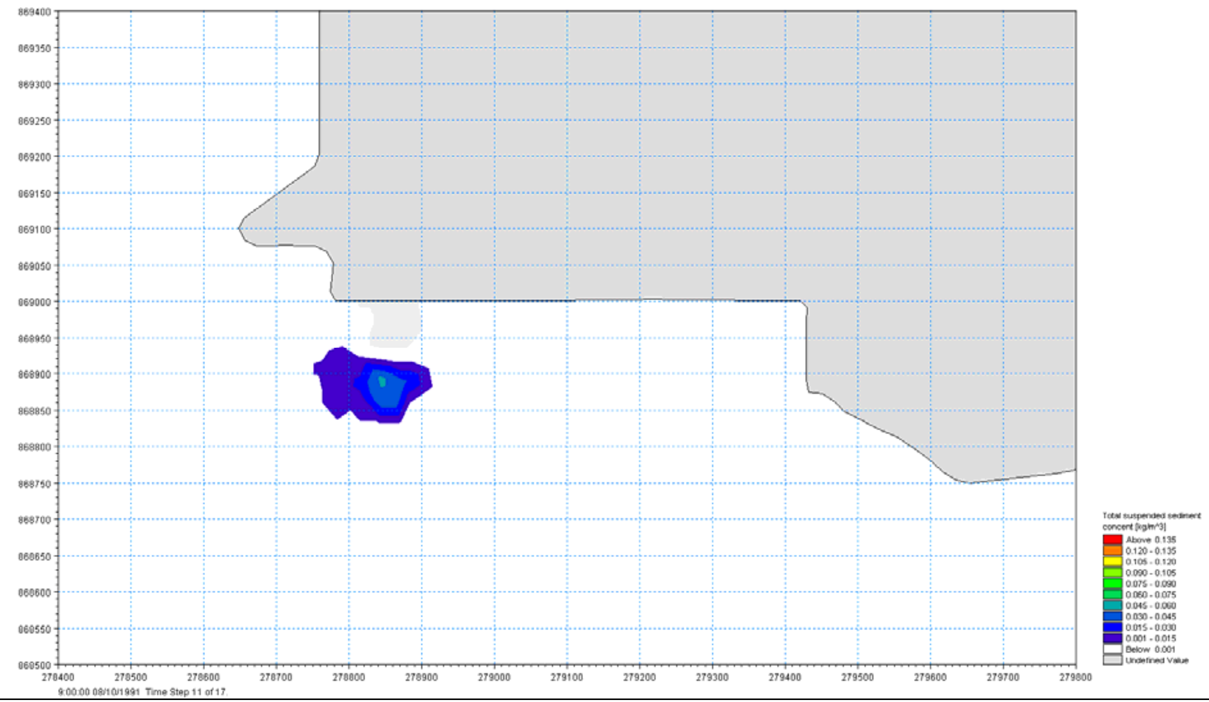
8 hours after start of release



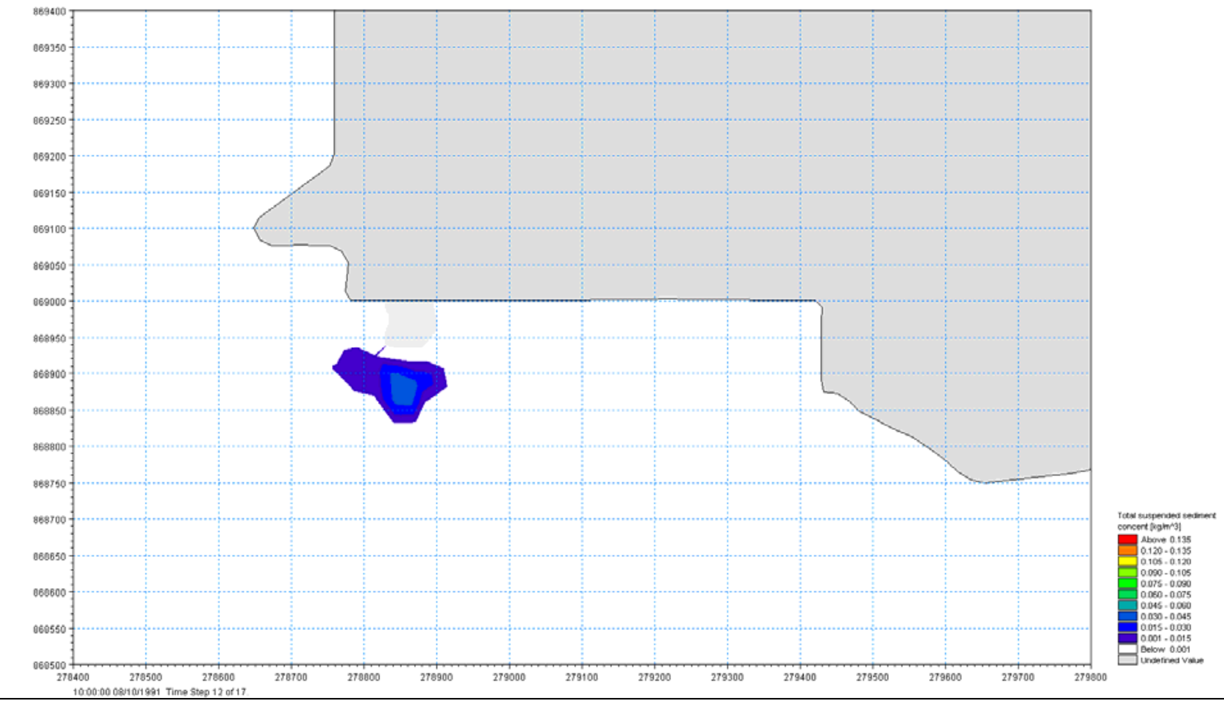
9 hours after start of release



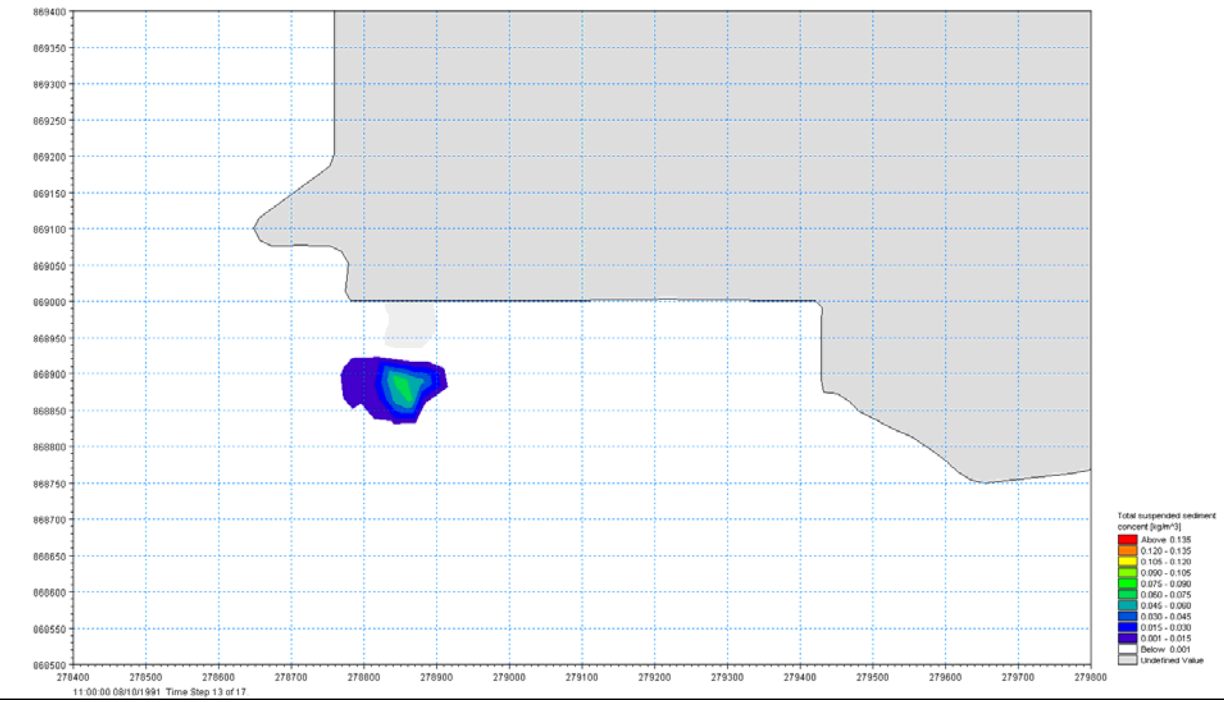
10 hours after start of release



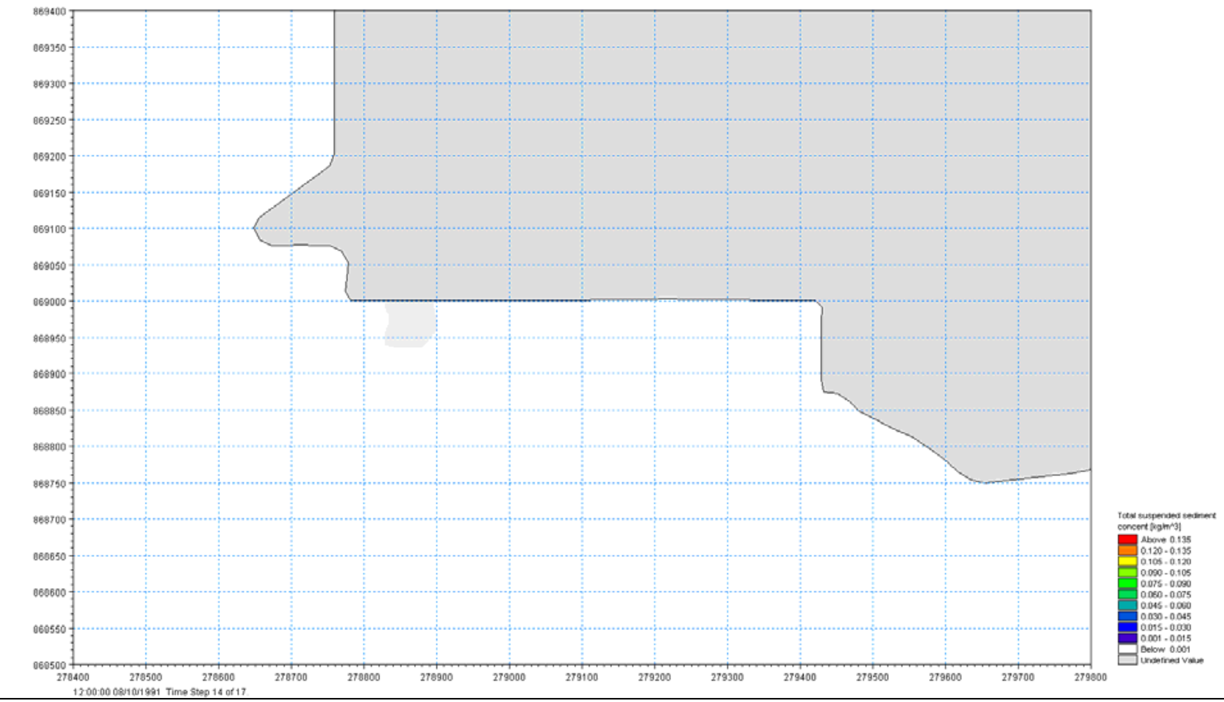
11 hours after start of release



12 hours after start of release



13 hours after start of release



14 hours after start of release