Marine dispersion modelling and impact assessment for landfill leachate chromium discharges to Saltom Bay from Rhodia, Whitehaven

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	Name	Signature	Date
Author:	S Vives Lynch		
Checked:	P Atkin		
Authorised:	A D Smith		

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Westlakes Scientific Consulting Ltd Westlakes Science & Technology Park Moor Row Cumbria CA24 3LN	Telephone: Fax: e-mail:

Executive Summary

Rhodia have one specific ongoing effluent resulting from leachate pumped from a closed landfill. Currently, this leachate is discharged as part of Huntsman's IPC permit. As this will no longer be valid for future operations, Rhodia have requested a water resources consent to discharge their landfill leachate out via the existing sea outfall, when Huntsman surrender their current IPPC permit for the sea outfall. The EA have in principle agreed with this approach, with the condition that Rhodia perform some dispersion modelling of Saltom Bay based on this one remaining effluent. The EA have also indicated chromium as being the element of relevance at the present time.

Previous modelling studies have been used to predict the impact of the discharge effluent on local SSSI sites and at the EQS point Tom Hurd Rock. These studies resulted in the production of minimum dilution factors at intervals of 200m up to 2.4 km from the discharge location for continuous discharges. In 2002, a baseline of prevailing environmental conditions along the coastal foreshore area around both the discharge point and Byerstread fault was performed. Data analysis showed that poorer ecological communities were always to the north/north-east of the discharge points. But further analysis indicated that there appeared to be some discrete discharges north of the site, which could be causing the high zinc, lead and cadmium monitoring data. The dilution factor data were then applied as part of a *Skeletonema costatum* and *Tisbe battagliai* DTA assessment to investigate the effect the discharges on the honeycomb worm (*Sabellaria alveolata*) in 2004 and showed that the Rhodia site discharge was at a sufficient dilution so as not to effect ecological communities at the site.

The initial 2002 dilution factor data are based on high flow continuous discharges. The proposed discharge regime is low flow and has a pulsed nature with a maximum effluent discharge of 50 m^3. The discharge may take place at any time due to being dependent on a holding tank level trigger. Hence, further modelling is required to determine the most appropriate environmental dilution around the discharge point for a low effluent flow, pulse discharge.

ELSID initial dilution modelling was performed for multiple tidal cycle phases and effluent flow rates from 5 $m^3 h^{-1}$ to 10 $m^3 h^{-1}$. For discharges during spring tides the minimum dilution factor ranges from 2.4 to 3.8 and occurs on a rising tide, while the maximum ranges from 368 to 232, and the mean from 164 to 104. For discharges during neap tides the minimum initial dilution factor ranges from 16 to 10, while the maximum ranges from 188 to 118 and the mean from 90 to 67. Maximum dilution always occurs during high spring tides while minimum dilution occurs during low spring tide due to the discharge pipeline being exposed. Higher dilution was always associated with low effluent flow rates.

Monte Carlo simulations were also performed using ELSID to predict the 95th percentile dilution factors for the effluent discharge. Excluding periods of pipeline exposure the 95th percentile dilution factor for discharge on spring and neap tides is 4 and 12 respectively.

MIKE21 was used to predict the environmental concentrations of effluent discharge based on three daily pulse discharges occurring at either rising, high water, falling or low water. Both spring and neap tidal conditions where modelled with a mean, 7.14 $m^3 h^{-1}$ and maximum, 10 $m^3 h^{-1}$ effluent flow rate and typical local wind conditions. The predicted maximum concentration field over six tidal cycles was analysed to determine both initial and environmental dilution factors. The minimum environmental dilution between the discharge location and Tom Hurd Rock was shown to be dependent on the discharge timing. For

maximum and average effluent flow rates the minimum environmental dilution occurred for high water discharge, while lower environmental dilution was predicted for discharge over neap tidal periods.

For the most conservative approach to applying the initial dilution factors it is recommended that the initial pipeline dilution be based on the ELSID predictions. This can be combined with the MIKE21 environmental dilution factor to obtain the effluent concentrations at the EQS point.

Application of this conservative approach to a discharge with a chromium concentration of 7.9 mg l^{-1} (the worst case landfill monitoring data), shows that for low water discharges the predicted environmental concentrations are in most cases above the recommended benchmark (EAL) for chromium in estuary and coastal waters of 15 $\mu g\ l^{-1}$. While for discharges on high water the predicted concentrations are an order of magnitude lower than the EAL value. However, the worst case landfill monitoring data corresponds to 2003 discharge levels. In 2005 the worst case effluent discharge (487 $\mu g\ l^{-1}$) was an order of magnitude lower than that associated with the landfill monitoring (7900 $\mu g\ l^{-1}$). Application of the dilution factors to the worst case 2005 discharge scenario predicts a range of environmental concentrations ranging from 0.03$\mu g\ l^{-1}$ to 1.09$\mu g\ l^{-1}$. These predicted values are below the chromium EAL.

Based on both the ELSID and MIKE21 modelling results the best initial and environmental dilutions would be achieved if discharges where only made during the period around high tide.

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1. Introduction

The Rhodia plant in Whitehaven discharges effluent from a single 600 mm diameter pipe under water at the base of the sea-cliffs, to the south of Whitehaven harbour. The discharge takes place close to a Site of Special Scientific Interest (SSSI), which has an extent of 170 ha. The specified Environmental Quality Standard (EQS) monitoring point for Rhodia discharges is at Tom Hurd Rock (Grid Reference NX 965 183). This point is located along the coast at approximately 2.25 km to the north of the discharge point.

Rhodia and Huntsman are in the process of decommissioning the site. Currently all water (process, domestic foul and surface) arisings go into Saltom Bay via a shared sea outfall. This is subject to an IPC permit held by Huntsman. Although Huntsman are to retain a small operation on site they are making arrangements for their domestic and process effluents to be discharged to sewer under a trade effluent consent with United Utilities.

Rhodia have one specific ongoing effluent resulting from leachate pumped from a closed landfill. Currently, Rhodia discharge this leachate as part of Huntsman's IPC permit for discharging this to sea. As this will no longer be valid for future operations, Rhodia have requested from the Environment Agency (EA) a water resources consent to discharge their landfill leachate out via the existing sea outfall, when Huntsman surrender their current IPC permit for the sea outfall.

The EA have, in principle, agreed with this approach, with the condition that Rhodia perform some dispersion modelling of Saltom Bay based on this one remaining effluent. The EA have also indicated chromium as being the element of relevance at the present time.

Rhodia considered it necessary to provide the EA with the following documentation as part of their discharge consent application:

- Review of previous dispersion modelling reports for Huntsman/Rhodia;
- Simple dilution-type calculations using the EA's preferred analytical model ELSID; and
- Dispersion modelling and impact assessment for chromium.

A MIKE21 50 m numerical grid model for the simulation of water levels and flows in coastal waters, previously developed for the Rhodia site at Whitehaven by Westlakes Scientific Consulting Ltd (Vives Lynch, 2001a), has been used for modelling the dispersion of chromium from the Rhodia landfill site.

2. Literature Review

A series of reports where highlighted by Rhodia for review prior to any further modelling being undertaken. These reports have been provided to WSC from Rhodia and reviewed in line with the following objectives:

- Extraction of appropriate monitoring data for chromium
- An initial assessment of the potential ecological impact of the proposed chromium discharges upon foreshore communities and local SSSI's.
- Assessment and conversion/scaling of the proposed discharge in order to define the potential impacts along the coast.

The reports cover three main areas of interest, namely the previous modelling work under taken by WSC, monitoring data in the form of ecological and multivariate surveys and a direct toxicity assessment of 2004 discharged effluent. Each of these have been reviewed and investigated in line with the objectives given above.

2.1 Chromium Monitoring

The EA have indicated that the chromium constituent of the effluent discharge is that which should be given consideration, with regard to environmental impacts. The environmental benchmark Environmental Assessment Level (EAL) for chromium in estuary and coastal waters is 15 $\mu g\ l^{-1}$ (EA, 2004).

The Rhodia chromium discharges dominate over other local discharges (Table 1). However, based on the landfill monitoring data (*pers. comm.*, Helen Stephenson), there appears to have been a reduction in the amount of chromium being discharged since 2002. The landfill cells are individually monitored for a range of different contaminants. The chromium data for the period August 2002 to May 2005 is shown in Table 2. The chromium monitoring data shows a distinct pattern of two sets of data pre August 2002 and post August 2002. The earlier data is between one and two orders of magnitude higher than the most recent monitoring data. For the post 2002 data, the maximum monitored concentration for chromium over all cells is 7.9 mg/l. The post August 2002 data is more appropriate to present conditions in the landfill; hence this value could be applied as a potential maximum concentration value for determination of environmental concentrations.

2.2 MIKE21 St Bees Head Model

Westlakes Scientific Consulting developed a hydrodynamic and advection dispersion model of the coastal area around the Whitehaven, Rhodia plant in 2001. This model was used to provide Rhodia with a modelling study of the effects of discharges from the Rhodia chemical works near Whitehaven to coastal waters around St Bees Head for their COMAH application. The MIKE21 model was used to simulate both continuous and pulsed discharges from the plant during a wind of 7.5 ms^{-1} from the south. The predicted concentrations at the discharge location, the EQS point (Tom Hurd Rock) to the north of the discharge point and two Sites of Special Scientific Interest to the south of the discharge point were extracted. This data was compared with LC_{50}, LD_{50} and UK EQS environmental protection parameters. In all cases the predictions for each pollutant were lower than the relevant environmental protection parameter. Float track predictions were also made for non-soluble discharges. These showed the pollutant remaining near the discharge location during neap tides and moving to the north during spring tides (Vives Lynch, 2001a).

The model was then applied to the modelling of copper discharges by simulating two different continuous discharge scenarios from the plant during a wind of 7.5 ms^{-1} from the south. The predicted concentrations at the discharge location and the EQS point (Tom Hurd Rock) were extracted. The model showed that changing the discharge regime while keeping the mass flux of copper constant has no effect on the final concentration field. Reducing the mass flux of copper being discharged results in a reduction of the concentration at both the discharge and EQS point. The resulting concentration data at the EQS point was compared with the lethal concentration at 50% (LC_{50}), lethal dose at 50% (LD_{50}) and EU/UK Environmental Quality Standard (EQS). These are all typical environmental protection parameters. For all discharge scenarios considered, the copper concentration predictions were lower than the relevant environmental protection parameters (Vives Lynch, 2001b).

The model was then used to determine the maximum copper effluent loading that would result in environmental concentrations equal to the specified copper EQS at Tom Hurd Rock. The MIKE21 model was used to simulate two different continuous discharge effluent flow scenarios, with a range of copper load concentrations from the plant during a wind velocity of 7.5 ms^{-1} from the south. The predicted concentrations at the EQS point (Tom Hurd Rock) were extracted and a trend line fitted to the data. The resultant trend line equations were used to determine the copper input, which would result in environmental EQS levels at Tom Hurd Rock. For both scenarios the predicted maximum mass flux of copper for spring tides was 2.6 kg h^{-1} while for neap tides the predicted maximum mass flux was 1.4 kg h^{-1}. The results for discharge on neap tides should be considered as the maximum effluent discharge concentration, which will give rise to EQS environmental concentrations at the EQS point. However, environmental concentrations at other locations, closer to the discharge point may significantly exceed the specified copper EQS value (Vives Lynch, 2002a).

Finally the model was used to determine dilution factors for conservative dissolved phase effluents, discharged via the marine pipeline into the Irish Sea, from the Huntsman plant near Whitehaven. A continuous discharge effluent flow scenario, with a load concentration of 1 kg h^{-1} and a flow rate of 200 m^3 h^{-1} from the plant during a worst case wind scenario of 7.5 ms^{-1} from the south was applied.

The concentration field over six tidal cycles for each run was extracted at a spatial resolution of 50 m and time intervals of 15 minutes for a box of dimension 5 km by 5 km centred on the discharge point. Data were analysed using a MIKE21 statistical toolbox to determine the maximum concentration within each 50 m grid cell over six tidal cycles. The maximum concentrations at 200 m intervals along four radial lines from the discharge point, namely north, north west, west, south west and the discharge to EQS point line was then extracted. These data were then collated and the maximum concentration at each radial distance determined. The concentration field over six tidal cycles for each run was extracted over the whole model area at a spatial resolution of 50 m and a time interval of 1 hour. Using the derived concentration field data and the known concentration loading, dilution factors were derived and presented as a look up table and a contour map for use by Huntsman environmental managers (Vives Lynch, 2002b).

The previous modelling work covered specific discharge scenarios, ranging from combined continuous and pulsed discharges to continuous discharge alone. The volumes being discharged are higher than the current landfill effluent holding tank maximum volume for discharge. Thus, these data cannot readily be applied to the current pulsed discharge scenario as they could potentially underestimate the minimum dilution factors.

Application of the dilution factors derived in Vives Lynch (2002b) results in an initial dilution factor of 44 for discharge during spring tides and 133 for discharge during neap tides, assuming a maximum discharge flow rate of 10 m^3 h^{-1}. Lower effluent flows would result in higher predicted dilutions.

However, it should be noted that these dilution factor data are based on continuous discharges. Hence, further modelling is required to determine the most appropriate environmental dilution around the discharge point for a low effluent flow, pulse discharge.

2.3 Ecological and Multivariate Surveys

In 2002, a baseline of prevailing environmental conditions along the coastal foreshore area around both the discharge point and Byerstread fault was investigated by Physalia (Physalia, 2002a). This monitoring study was based on meiofauna to be found in the foreshore sediments due to their rapid response to short term changes in environmental conditions. Three samples were taken for each site so as to investigate the ecological, physical and chemical characteristics of the foreshore area. The resultant monitoring data for chromium are given in Table 3 and the discharge locations are given in Figure 2.

Although, data analysis showed that poorer ecological communities were always to the north/north-east of the discharge points, further analysis indicated that the poor meiofauna results may not be associated with the pipeline and Byerstead Fault discharges. The results indicated that there appeared to be some discrete discharges north of the site, which could be causing the high zinc, lead and cadmium monitoring data (Physalia, 2002b).

2.4 Direct Toxicity Assessments

As part of a PPC permit improvement scheme, in 2004 the Huntsman effluent discharge to the Irish Sea was analysed for ecotoxicity (AstraZeneca, 2004) In particular, Direct Toxicity Assessments (DTA) were performed for *Skeletonema costatum* and *Tisbe battagliai*, with a view to investigations of the effect the discharges on the honeycomb worm (*Sabellaria alveolata*) reefs south of the St Bees Head.

The results concluded that under EA guidelines, applicable at that time, the effluent was toxic as the "No Observed Effect Concentration" was never above 1%. The worst case being 0.032%, this equates to a required dilution of 3125 to ensure no effect to algae. This dilution factor was compared with the predicted MIKE21 dilution factor of 5675 based on an effluent flow rate of 65 m^3 h^{-1} during spring tide (Vives Lynch, 2002) for a point 2.4 km from the discharge point. The dilution predicted by the model exceeds that required for no effect to algae.

The dilution factors applied above are based on a continuous effluent flow rate. It is feasible that a pulsed discharge would result in a greater initial dilution of the effluent discharge in the environment. But this might be dependent on the pulse length and timing with respect to the tidal state.

In parallel to the DTA assessment, the effluent was also assessed over the June 2004 sampling period for a range of chemical parameters including chromium. These results are presented in Table 4. Comparison of the sample data with the landfill monitoring data for 2004 indicates that chromium concentrations in the DTA effluent samples where at least one order of magnitude lower than those taken during the previous week from the landfill.

3. Model description and parameters

3.1 ELSID Initial Dilution Modelling

The ELSID (EvaLuation and Simulation of Initial Dilution) model was designed to provide users with a simple tool to undertake assessments of the initial dilution of effluent from marine discharges. It was proposed that the current Rhodia landfill effluent discharge be modelled for discharge into tidal waters. A Monte Carlo simulation of initial dilution was also performed to obtain 95th percentile compliance.

3.1.1 Multiple tidal water dilution calculations

Initial dilutions were calculated for a range of tidal currents and depths at the discharge point. The tidal information was derived from a MIKE21 hydrodynamic model run and used as input parameters for the ELSID model.

MIKE21 tidal information predicts the total water depth in the cell corresponding to the discharge point. The ELSID model works with the depth of water above the discharge pipeline. The Rhodia discharge pipeline is 0.5 m above the seabed, hence the MIKE21 depth data has been adjusted accordingly. Both spring and neap tide scenarios were modelled. Each covered a full tidal cycle with a thirty-minute interval and corresponded to a low neap and high spring tide respectively.

The model was run for a range of effluent flow rates, namely 5, 6, 7, 8, 9 and 10 m^3 h^{-1}. The initial dilution data for one tidal cycle was calculated and analysed for the predicted maximum, mean and minimum dilutions for each discharge flow rate and tidal state.

It was assumed that the receiving water density was 1.026 (the density of seawater) while the effluent relative density was 1.000 (the density of freshwater). These are the default density parameters provided by ELSID.

3.1.2 Monte Carlo simulations of initial dilution

Monte Carlo initial dilution simulations allow the calculation of percentile initial dilutions from:

- Normal probability distributions of the effluent flow rate,
- Log-normal probability distributions of the effluent flow rate
- Flow rate generated according to the pump duty cycle of the treatment works,
- Values can be selected at random from a file of flow rate values.

Normal and log-normal probability distributions are described by their mean and either the standard deviation or the 95th percentile.

It was proposed that the pump duty cycle flow data be used for these simulations. However, the discharge pump work does not follow a duty cycle and effluent is typically discharged at a rate between 5 and 10 m^3 h^{-1} with a potential maximum flow rate of 12 m^3 h^{-1} (*pers. comm.* Helen Stephenson). Hence, it is more appropriate to calculate the percentile dilutions based on the random selection of flow rate values. An effluent flow rate input file for discharges at 5, 6, 7, 8, 9, 10 and 12 m^3 h^{-1} was set-up and applied for the Monte Carlo simulations. The 12 m^3 h^{-1} effluent flow rate being included as an extreme maximum flow rate,

Both spring and neap current and water depth values, obtained from the MIKE21 hydrodynamic model and used for the ELSID initial dilution modelling were also applied to the Monte Carlo simulations. Simulation was specified for a single output port and both 1,000 and 10,000 iteration simulations were performed. The simulation output for percentile dilutions was derived at 5 % intervals from 5 % to 100%.

3.2 MIKE21 Chromium Modelling

The previous modelling work performed to determine initial dilution data was based on a continuous discharge of effluent. The proposed discharge regime is a pulse discharge, which may occur on any tidal phase due to the tank discharge being based on a maximum volume switch. For this case the previous modelling work is not readily applicable and may even result in an under estimation of the predicted dilutions. Hence, updated dilution data based on low volume pulse discharges is required.

3.2.1 Model set-up

The MIKE21 50 m St Bees Head model, shown in Figure 1, was set up using the same base parameters as used for previous MIKE21 Rhodia EQS work (Vives Lynch, 2001a). This included a wind speed of 7.5 ms^{-1} and wind direction of 235^o.

A maximum discharge of 50 m^3 from the effluent treatment tank can be discharged at any time to sea and typically a maximum pump rate of 10 $m^3 h^{-1}$ can be applied. However, the average case pump rate is about 7 $m^3 h^{-1}$. The holding tank discharges on a trigger system and could potentially discharge to sea on a daily rate, if high rainwater run-off is considered. As a worst case scenario a possibility of three daily discharges was modelled, this should result in a conservative estimate of the potential dilution of the effluent in the receiving waters.

A single discharge source, set-up at location NX 9606 1627 has been modelled using the following discharge scenarios:

- Daily discharge centred on high, falling, low and rising water for a neap tidal period
- Daily discharge centred on high, falling, low and rising water for a spring tidal period

Each scenario was run for both the average and maximum pump flow rates. The maximum flow rate of 10 $m^3 h^{-1}$ results in a 5 h discharge window. By applying a discharge rate of 7.14 $m^3 h^{-1}$ for the average flow a discharge window of 7 h may be applied. This was discussed with Rhodia environmental managers and was agreed as an acceptable average flow rate for the MIKE21 modelling work (*pers. comm.*, Helen Stephenson).

The effluent being discharged consists of leachate pumped from the landfill cells and rainwater from a surface drain at the base of the landfill. This implies that some dilution of the effluent may occur in the holding tanks prior to primary treatment and subsequent discharge to sea. Therefore, a conservative approach has been taken for the determination of the chromium concentration in the effluent discharge. Data on effluent concentrations is currently obtained from each of the landfill cells, the final leachate being a variable mixture from all the cells. It was proposed that the maximum concentration measured over all cells be applied to the volume of effluent in the holding tank and that no dilution with rainwater would be considered at this stage.

Rhodia supplied the landfill effluent concentrations in each cell for the period October 2000 to May 2005. Analysis of the chromium data showed that a change in the discharge concentration took place in June 2002, concentrations after June 2002 where between one and three orders of magnitude lower than previously monitored.

The model was initially run using a unit discharge concentration and the actual chromium discharge concentration was applied to the initial results to obtain the model predicted environmental concentrations.

The maximum concentration field over six tidal cycles for each run was determined. These data were then analysed for both the maximum concentrations at both the discharge point and at the EQS monitoring point. From this data, dilution factors were determined for each discharge scenario.

4. Results and Discussion

4.1 ELSID Initial Dilution Modelling

4.1.1 Multiple tidal water dilution calculations

The ELSID model predictions for multiple tidal cycle initial dilution for effluent discharge over both spring and neap tidal cycles are given in Table 5 and Table 6 respectively. The maximum, mean and minimum initial dilutions have been extracted for each tidal discharge scenario and are given in Table 7.

For all effluent flow rates the minimum dilution for discharge during spring tide is zero. This is due to the discharge pipeline being exposed during low spring tides. Excluding periods when the discharge pipeline is exposed, the minimum dilution factor ranges from 2.4 to 3.8 and occurs on a rising tide. The maximum initial dilution factor during spring tides ranges from 368 to 232, with a greater dilution occurring for the lower effluent flow rates. The mean initial dilution factor over the full tidal cycle ranges from 164 to 104, with the higher dilution being associated with the low effluent flow rates.

For discharges during neap tides the minimum initial dilution factor ranges from 16 to 10, while the maximum ranges from 188 to 118 and the mean from 90 to 67. The higher dilutions again being associated with low flow effluent discharge rates.

Comparison of predicted initial dilution factors for spring and neap tides shows that the highest dilution always occurs during spring tides. This is due to the volume of water the effluent is discharged into being at a maximum during the high spring tides and higher tidal velocities.

4.1.2 Monte Carlo simulations of initial dilution

The ELSID Monte Carlo initial dilution predictions are given in Table 8. The percentile dilutions, in 5% increments, derived for both 1,000 and 10,000 iterations and result in similar initial dilution factors. The 95th percentile initial dilution is defined by the Environment Agency as the reduction in concentration that the discharge will receive between the point of discharge and the open sea surface for 95% of the time.

Percentile values are usually defined as follows; for a value corresponding to the 95th percentile, 95% of values will be less than the 95th percentile value and 5% of values will be greater than this value. Hence, the 95th percentile value for initial dilutions required by the EA corresponds to the ELSID 5th percentile Monte Carlo results.

From Table 8 the 95th percentile initial dilution factor during spring tide is 2 and for neap tide the initial dilution factor is 12. The value predicted for spring tides includes periods with the discharge pipeline being exposed during low spring tides. Rerunning the Monte Carlo simulation for the tidal period in which the discharge pipeline is always below the water level results in the ELSID percentile predictions given in Table 9. For this scenario the 95th percentile for the initial dilution factor is 4.

The calculated 95th percentile should be viewed with some caution due to the tidal velocity and elevation data being derived from the MIKE 21. The St Bees Head model has a grid size of 50 m and therefore tidal elevation and velocity data are averaged throughout the water column. Such spatial averaging may lead to discrepancies from the actual tidal velocity and elevation at the point of discharge.

4.2 MIKE21 Chromium Dispersion Modelling

The results of the MIKE21 modelling are given in Table 10. Minimum initial dilution factors from effluent holding tank to the discharge point and the EQS point, Tom Hurd Point, have been calculated based on the maximum predicted environmental concentrations. These data have been used to calculate the environmental dilution factor between discharge and EQS point.

Analysis of the initial dilution at the discharge point shows the least dilution occurs when the discharge occurs over low water on both spring and neap tides for high effluent flow rates. While for the average effluent flow the minimum dilution occurs on falling water.

Comparison of the initial dilutions over spring and neap tidal cycle shows that dilution predictions for spring tide discharges are lower than those for neap tide, this is due to the potential for the discharge pipeline to be exposed during low spring tides. This result is comparable to that predicted by ELSID for minimum dilutions. However the MIKE21 initial dilutions are at least an order of magnitude greater than the ELSID predictions. This is possibly due to the MIKE21 discharge being instantly diluted by the full volume of the model cell.

The minimum environmental dilution between the discharge location and Tom Hurd Rock is dependent on the discharge timing. For maximum and average effluent flow rates the minimum environmental dilution occurs for high water discharge. Lower environmental dilution is predicted for discharge over neap tidal periods.

4.3 Potential Impact of Chromium Discharges

Applying a conservative approach, the effluent concentration at Tom Hurd Rock can be predicted using a combination of the ELSID initial dilution factors and MIKE21 Environmental dilution factors. ELSID predicts minimum dilutions for discharges at low water and maximum dilution for discharge at high water. These values were applied to obtain the potential range of final dilutions and hence environmental concentrations based on the worst case landfill monitoring data of 7.9 mg l^{-1}.

The results, shown in Table 11, show that for low water discharges the predicted environmental concentrations are in most cases above the recommended benchmark (EAL) for chromium in estuary and coastal waters of 15 µg l^{-1}. While for discharges on high water the predicted concentrations are an order of magnitude lower than the EAL value. However, it should be noted that this worst case scenario occurred in 2003, a comparison of the annual discharge data available (Table1) shows that the more recent 2005 chromium discharges are lower. The chromium effluent concentrations, were supplied to Rhodia, by Huntsman for 2005 (*pers. comm.,* Helen Stephenson). Analysis of the 2005 discharge data, Table 12, shows that the worst case effluent discharge was 487 µg l^{-1}. Application of the dilution factors to this discharge scenario (Table 13) predicts a range of environmental concentrations ranging from 0.03µg l^{-1} to 1.09µg l^{-1}. These predicted values are below the chromium EAL.

The application of the dilution factors is based on worst case scenario for Tom Hurd Rock and is not necessarily the worst case for the *Sabellaria alveolata* south of St Bees. The wind direction applied in the model is based on the most common wind direction and is from the south-west, while wind speed is representative of a moderate to strong wind. There is the potential that under different wind conditions the effluent may come in contact with the *Sabellaria alveolata* at lower dilutions than currently predicted.

5. Conclusions

The current discharge regime is a trigger system based on tank volume. There is the possibility that discharges could occur during very low spring tides and hence no initial dilution of the effluent in the environment would occur.

The MIKE21 predicted initial dilution factors are up to two orders of magnitude greater than those predicted by ELSID. This may be attributed to the effluent being instantaneously diluted by the total cell volume in the MIKE21 model.

For the most conservative approach to applying the initial dilution factors it is recommended that the initial pipeline dilution be based on the ELSID predictions. This can be combined with the MIKE21 environmental dilution factor to obtain the effluent concentrations at the EQS point.

In the case of the MIKE21 modelling the environmental dilutions are based on a worst case scenario of three pulse discharges occurring over three tidal cycles and the assumption that the effluent holding tank takes at least one tidal cycle to refill prior to further discharge.

Based on both the ELSID and MIKE21 modelling results the best initial and environmental dilutions would be achieved if discharges where only made during the period around high tide. This would also ensure that no discharge takes place when the pipeline is exposed during low spring tides.

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Table 1: Annual load for local chromium discharges

Year	Effluent load kg	
	Rhodia	**Sellafield**
2000	n/a	40
2001	n/a	38
2002	n/a	34
2003	890	23
2004	n/a	n/a
2005	36	n/a

n/a: data not available

Table 2: Landfill leachate chromium monitoring

DATE	Cell 1/4	Cell 2/3	Cell1	Cell 2	Cell 3	Cell 4	Cell 5
	mg l^{-1}						
25-Oct-00			10	13	12	4480	
20-Mar-02			1180	4650	3000	4900	
28-Aug-02	2	3.2					1.30
25-Sep-02	2.1	3.5					1.50
29-Oct-02	2.2	4.5					1.60
27-Nov-02	3.4	5.6					2.00
16-Apr-03	2.1	2.9					1.90
23-Apr-03	3.0	3.0					2.00
30-Apr-03	1.9	1.5					2.50
06-May-03	1.9	2.7					1.50
28-May-03	0.07	7.9	3.4	6	6.2	6.7	4.40
26-Nov-03	<0.01	2.6					0.07
26-May-04	0.26	3.1	0.12	2.7	3.6	2.7	0.03
29-Sep-04	<0.01	<0.01					0.01
26-Oct-04	0.04	2.5					0.09
25-Nov-04	1.80	2.6					1.10
23-Feb-05							1.5
18-May-05	2.1	3.2	0.16	2.6	3.7	3	

Table 3: Chromium sediment concentration around the Whitehaven coast, September 2002

Location	**Sediment Metal Concentration µg g^{-1}**	
	Outfall	**Fault**
A	6.40	8.52
B	6.79	6.65
C	7.81	6.76
D	7.29	6.64
E	6.02	6.72
F	6.52	6.43
G	7.38	6.94

Table 4: Chromium concentrations in effluent DTA samples

Sample Date	**Effluent Concentration µg l^{-1}**
01.06.04	31.6
02.06.04	32.8
03.06.04	47.1
04.06.04	42.7

Table 5: ELSID Multiple Tidal Cycle Initial Dilutions for Discharge during Spring Tides

ELSID Tidal State	Depth	Speed	Effluent flow rate $m^3\,h^{-1}$					
	m	$m\,s^{-1}$	5	6	7	8	9	10
1	0	0	0	0	0	0	0	0
2	0.461429	0.013033	3.8	3.4	3	2.8	2.6	2.4
3	1.13907	0.006852	17.1	15.1	13.7	12.5	11.6	10.8
4	2.13674	0.013076	48.8	43.2	39	35.7	33	30.7
5	3.12156	0.028779	91.7	81.2	73.3	67.1	62	57.8
6	4.19051	0.034818	149.9	132.7	119.8	109.5	101.3	94.4
7	5.14926	0.033345	211.3	187.1	168.8	154.4	142.8	133.1
8	6.0506	0.033665	276.4	244.8	220.9	202.1	186.8	174.2
9	6.76397	0.012676	332.8	294.7	266	243.3	224.9	209.7
10	7.09798	0.013034	360.7	319.4	288.2	263.7	243.7	227.2
11	7.18325	0.020157	367.9	325.8	294	269	248.6	231.8
12	6.86081	0.008014	340.8	301.8	272.4	249.2	230.3	214.7
13	6.40064	0.029463	303.6	268.8	242.6	221.9	205.2	191.3
14	5.6899	0.010416	249.5	220.9	199.4	182.4	168.6	157.2
15	4.94085	0.034487	197.2	174.6	157.6	144.2	133.3	124.2
16	4.09759	0.050805	144.4	127.8	115.4	105.5	97.6	91
17	3.32277	0.029934	101.8	90.1	81.4	74.4	68.8	64.1
18	2.36971	0.034712	58	51.3	46.3	42.4	39.2	36.5
19	1.41044	0.044473	24.4	21.6	19.5	17.8	16.5	15.4
20	0.76748	0.016667	8.9	7.8	7.1	6.5	6	5.6

Table 6: ELSID Multiple Tidal Cycle Initial Dilutions for Discharge during Neap Tides

ELSID Tidal State	Depth	Speed	Effluent flow rate $m^3 h^{-1}$					
	m	$m s^{-1}$	5	6	7	8	9	10
1	1.07617	0.006028	15.5	13.8	12.4	11.4	10.5	9.8
2	1.10587	0.006344	16.3	14.4	13	11.9	11	10.3
3	1.30313	0.007382	21.4	18.9	17.1	15.6	14.5	13.5
4	1.52245	0.00441	27.7	24.5	22.2	20.3	18.7	17.5
5	1.92128	0.002897	40.9	36.2	32.6	29.9	27.6	25.7
6	2.28969	0.002591	54.7	48.5	43.7	40	37	34.5
7	2.75562	0.007207	74.5	66	59.6	54.5	50.4	46.9
8	3.18858	0.011244	95	84.2	75.9	69.9	64.2	59.9
9	3.64064	0.018	118.5	105	94.7	86.7	80.1	74.7
10	4.14081	0.016421	146.9	130.1	117.4	107.4	99.3	92.6
11	4.46459	0.017066	166.5	147.5	133.1	121.7	112.5	104.9
12	4.70892	0.011679	182	161.2	145.5	133.1	123	114.7
13	4.79472	0.004216	187.6	166.1	149.9	137.1	126.8	118.2
14	4.77723	0.001596	186.4	165.1	149	136.3	126	117.5
15	4.62865	0.002416	176.9	156.6	141.3	129.3	119.5	111.4
16	4.39713	0.006819	162.4	143.8	129.8	118.7	109.7	102.3
17	4.10361	0.002008	144.7	128.1	115.6	105.8	97.8	91.2
18	3.71849	0.006237	122.8	108.7	98.1	89.8	83	77.4
19	3.3363	0.01204	102.5	90.8	81.9	74.9	69.3	64.6
20	2.85726	0.021104	79.2	70.1	63.3	57.9	53.5	49.9
21	2.44775	0.014455	61.2	54.2	48.9	44.7	41.3	38.5
22	2.07467	0.023064	46.4	41.1	37.1	33.9	31.4	29.3
23	1.68767	0.009458	32.9	29.1	26.3	24.1	22.2	20.7
24	1.4466	0.014615	25.5	22.5	20.3	18.6	17.2	16
25	1.26838	0.010009	20.4	18.1	16.3	14.9	13.8	12.9
26	1.26687	0.00673	20.4	18.1	16.3	14.9	13.8	12.9

Table 7: ELSID Multiple Tidal Cycle Initial Dilutions Data Analysis

Effluent Flow Rate	Spring Tide			Neap Tide		
$m^3 h^{-1}$	Minimum Dilution[1]	Mean Dilution	Maximum Dilution	Minimum Dilution	Mean Dilution	Maximum Dilution
5	3.8	164	368	16	90	188
6	3.4	146	326	14	94	166
7	3	131	294	12	85	150
8	2.8	120	269	11	78	137
9	2.6	111	249	11	72	127
10	2.4	104	232	10	67	118

[1] Zero dilution corresponding to pipeline exposure has been excluded

Table 8: ELSID initial dilution based on Monte Carlo simulation

ELSID Percentile	Spring Tide	Neap Tide
5	2	12
10	5	14
15	10	16
20	15	18
25	27	21
30	42	26
35	57	33
40	74	41
45	92	49
50	110	58
55	133	66
60	154	78
65	174	90
70	190	98
75	205	105
80	225	116
85	245	126
90	270	137
95	305	157
100	370	370

Table 9: ELSID Initial Dilution based on Monte Carlo Simulation for discharges on spring tide with the discharge pipeline below water at all time.

ELSID Percentile	Spring Tide
5	4
10	9
15	14
20	22
25	36
30	49
35	64
40	81
45	98
50	118
55	133
60	155
65	175
70	198
75	212
80	230
85	249
90	273
95	305
100	370

Table 10: MIKE21 Dilution Factors

Tide	Effluent Flow Rate $m^3 h^{-1}$	Tidal State	Initial Dilution from tank to		Environmental Dilution from
			Discharge Point	Tom Hurd Rock	Discharge Point to Tom Hurd Rock
Neap Tide	**10**	**LW**	1100	60265	55
		Rising	1822	92414	51
		HW	2827	84019	30
		Falling	1163	64328	55
	7.14	**LW**	1045	46708	45
		Rising	1379	59971	43
		HW	2273	61633	27
		Falling	*930*	*46107*	50
Spring Tide	**10**	**LW**	687	143771	209
		Rising	982	198567	202
		HW	*6032*	*707347*	117
		Falling	706	116210	165
	7.14	**LW**	658	98270	149
		Rising	982	195643	199
		HW	5078	252284	50
		Falling	413	112038	271

Table 11: Predicted range of dilution and chromium concentrations at Tom Hurd Rock

Tide	Effluent Flow Rate $m^3 h^{-1}$	Tidal State	ELSID Initial Dilution Factor	Environ-mental Dilution Factor	Predicted Dilution	Effluent Concentration	Predicted Environmental Concentration
			Discharge Point	Discharge Point to Tom Hurd Rock	Effluent Tank to Tom Hurd Rock	mg/l^{-1}	mg/l^{-1}
Neap Tide	**10**	**LW**	10	55	550	7900	14
	10	**HW**	118	30	3540	7900	2
	7	**LW**	12	45	540	7900	15
	7	**HW**	150	27	4050	7900	2
Spring Tide	**10**	**LW**	2.4	209	502	7900	16
	10	**HW**	232	117	27144	7900	0
	7	**LW**	3	149	447	7900	18
	7	**HW**	294	50	14700	7900	1

Table 12: Huntsman effluent chromium discharge analysis for 2005.

Date 4 weekly blend ending	Outlet Flow (ML)	Cr (kgs)	Cr(ug/l)
28-01-05	31.275	1.995	63.8
25-02-05	25.411	2.457	96.7
25-03-05	22.311	4.953	222
22-04-05	30.539	3.665	120
20-05-05	26.487	2.887	109
17-06-05	26.645	3.117	117
15-07-05	21.731	1.684	77.5
13-08-05	19.05	5.906	310
09-09-05	14.787	7.201	487
06-10-05	12.61	0.738	58.5
04-11-05	27.698	1.26	45.5
02-12-05	13.034	0.258	19.8
30-12-05	6.265		

Table 13: Predicted range of dilution and chromium concentrations at Tom Hurd Rock for the worst case 2005 discharge data

Tide	Effluent Flow Rate $m^3 h^{-1}$	Tidal State	ELSID Initial Dilution Factor	Environ-mental Dilution Factor	Predicted Dilution	Effluent Concentration	Predicted Environmental Concentration
			Discharge Point	Discharge Point to Tom Hurd Rock	Effluent Tank to Tom Hurd Rock	mg/l^{-1}	mg/l^{-1}
Neap Tide	**10**	**LW**	10	55	550	487	0.89
	10	**HW**	118	30	3540	487	0.14
	7	**LW**	12	45	540	487	0.90
	7	**HW**	150	27	4050	487	0.12
Spring Tide	**10**	**LW**	2.4	209	502	487	0.97
	10	**HW**	232	117	27144	487	0.02
	7	**LW**	3	149	447	487	1.09
	7	**HW**	294	50	14700	487	0.03

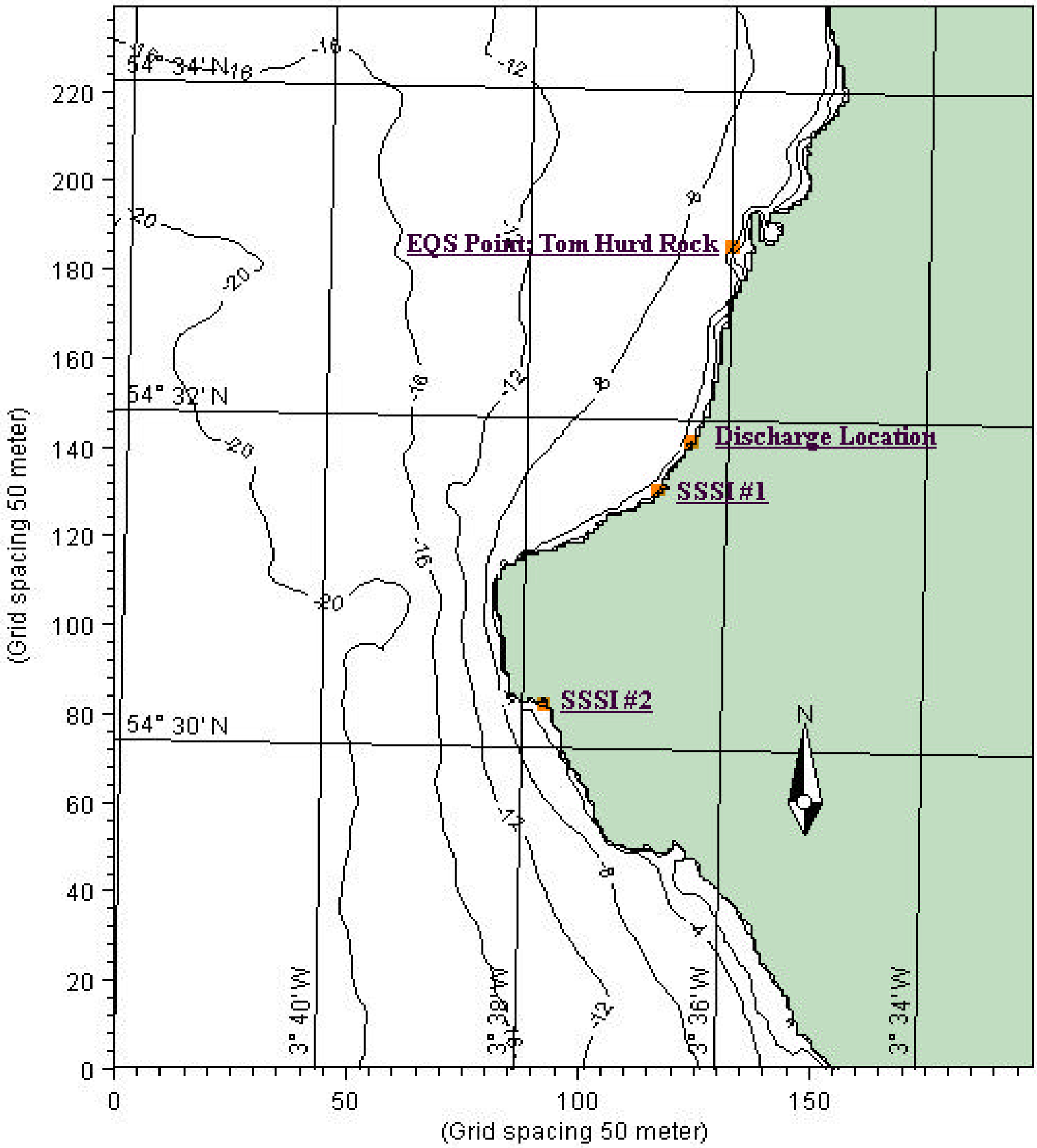

Figure 1: St Bees Head 50m Grid

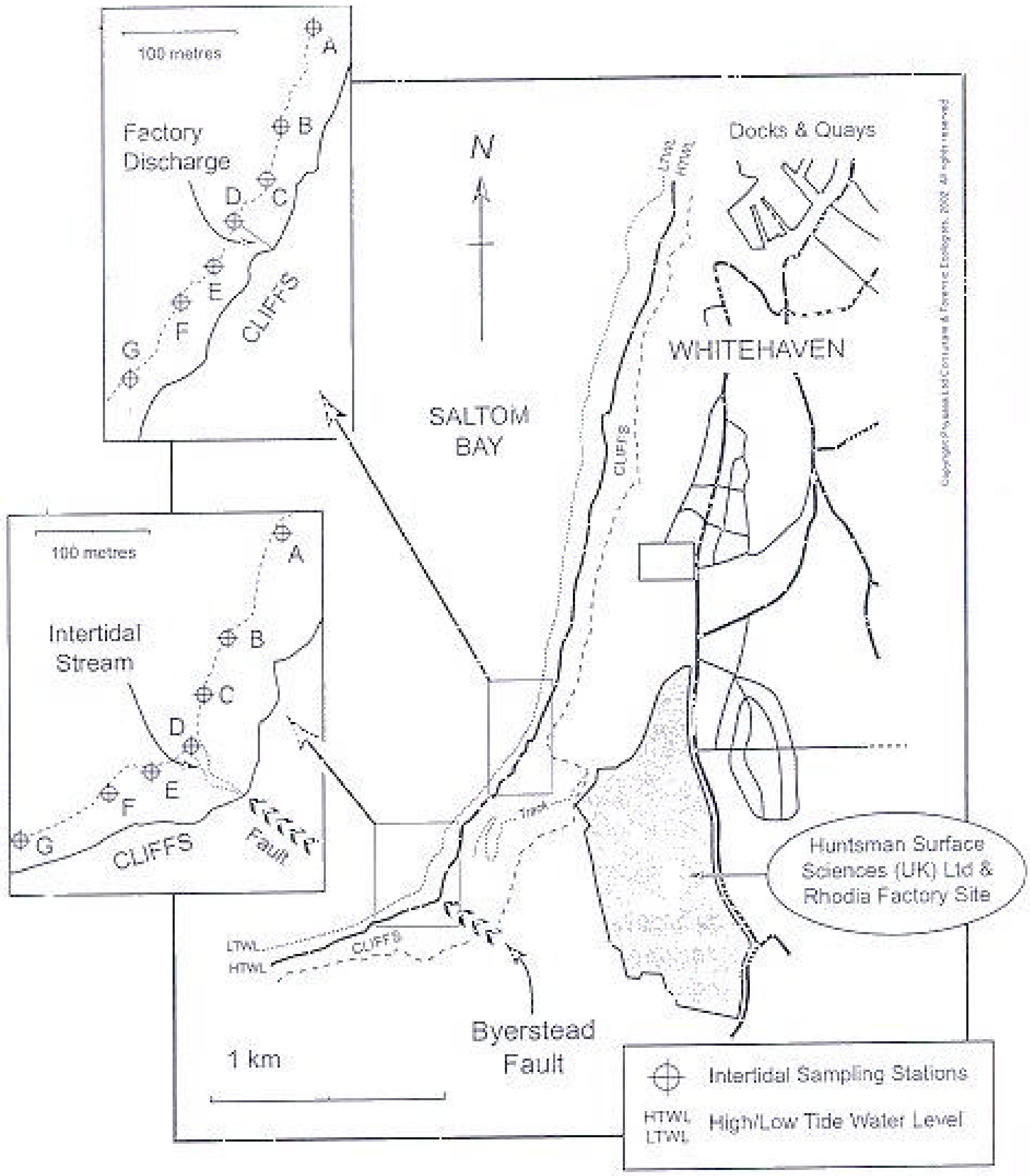

Figure 2: Monitoring locations used in the Physalia pilot ecological study (Physalia, 2002)