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Corrib Offshore Gas Field Development Produced Water Dispersion Assessment

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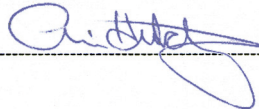
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Summary

Corrib Offshore Gas Field Development

Produced Water Dispersion Assessment

Report EX 5927

December 2008

RSK Environment Ltd (RSK) is working with Shell on the Corrib Offshore Gas Field Development. A discharge of produced water is proposed, in around 350m water depth, and RSK required a study to assess how quickly discharge constituent (for example, metals) concentrations are likely to reduce to near-background values.

It is understood that discharge will take place approximately 2m above the seabed, possibly beneath a protection cover. The maximum discharge flow rate is to be 65m³/day. Under normal operating conditions the discharge will be positively-buoyant; that is, the density of the discharge will be lower than that of the ambient seawater at the discharge point.

An assessment of the dispersion of the produced water has been undertaken. The results of mixing zone modelling indicate that, for the range of conditions assessed, predicted concentrations of each of the discharge constituents can be reduced to within 10% of background values up to 300m downstream, to within 5% of background values up to 500m downstream, and to within 1% of background values up to 1600m downstream of the discharge location. It should be noted, however, that for many of the discharge constituents, significantly smaller mixing zones are required to reduce concentrations to values approaching background concentrations.

The results of the present modelling have been obtained assuming that the produced water is discharged vertically into an unbounded seawater environment, and it should be considered when using the results in this report that dilution rates may vary if the discharge is located under a protection cover.

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1. *Introduction*

1.1 BACKGROUND

This report describes work commissioned by RSK Environment Ltd (RSK) in November 2008.

RSK is working with Shell on the Corrib Offshore Gas Field Development. A discharge of produced water is proposed, in around 350m water depth, and RSK required a study to assess how quickly discharge constituent (for example, metals) concentrations are likely to reduce to near-background values.

It is understood that discharge will take place approximately 2m above the seabed, possibly beneath a protection cover. The maximum discharge flow rate is to be 65m³/day. Under normal operating conditions the discharge will be positively-buoyant; that is, the density of the discharge will be lower than that of the ambient seawater at the discharge point.

This report presents the methodology and results of the assessment undertaken.

1.2 SCOPE OF WORK

Modelling was required to assess the dispersion of produced water for the proposed “normal” discharge scenario, with a maximum flow rate of 65m³/day. The concentration of each discharge constituent was provided by RSK (see Chapter 2).

1.3 REPORT STRUCTURE

Chapter 2 of this report describes the findings of a review of data supplied by RSK. Chapter 3 introduces the modelling tools used in this study, and the results of the produced water dispersion assessment are presented in Chapter 4. The conclusions of the study are stated in Chapter 5.

2. *Data assessment*

2.1 AMBIENT CONDITIONS

2.1.1 *Currents*

RSK provided HR Wallingford with the results of a field study for the Corrib development (Reference 1). Current data is presented as a frequency table for different speeds and directions over a year of observations. Currents were measured at 10m above the seabed, but Reference 1 takes the values as valid at 1m, without reduction, to allow a small margin of safety for structural design/stability issues. This data is summarised in Table 2.1.

Table 2.1 Year-long near-bed current observations (adapted from Reference 1)

Observed current direction (towards, °N)		Observed current speed (m/s)				Total occurrence
		0.0<0.1	0.1<0.2	0.2<0.3	0.3<0.4	
000<022.5	number	549	1268	303	13	2133
	%	3.5	8	1.9	0.1	13.5
022.5<045	number	734	1359	132	13	2238
	%	4.6	8.6	0.8	0.1	14.1
045<067.5	number	676	942	43	1	1662
	%	4.3	6	0.3	<0.05	10.6
067.5<090	number	611	690	12	-	1313
	%	3.9	4.4	0.1	-	8.4
090<112.5	number	622	559	8	-	1189
	%	3.9	3.5	0.1	-	7.5
112.5<135	number	518	412	14	-	944
	%	3.3	2.6	0.1	-	6
135<157.5	number	551	623	44	-	1218
	%	3.5	3.9	0.3	-	7.7
157.5<180	number	571	809	77	-	1457
	%	3.6	5.1	0.5	-	9.2
180<202.5	number	352	320	70	1	743
	%	2.2	2	0.4	<0.05	4.6
202.5<225	number	181	78	1	-	260
	%	1.1	0.5	<0.05	-	1.6
225<247.5	number	134	17	-	-	151
	%	0.8	0.1	-	-	0.9
247.5<270	number	103	8	-	-	111
	%	0.7	0.1	-	-	0.8
270<292.5	number	124	27	-	-	151
	%	0.8	0.2	-	-	1
292.5<315	number	198	56	-	-	254
	%	1.3	0.4	-	-	1.7
315<337.5	number	329	262	23	1	615
	%	2.1	1.7	0.1	<0.05	3.9
337.5<360	number	440	774	128	10	1352
	%	2.8	4.9	0.8	0.1	8.6
Total occurrence	number	6693	8204	855	39	15791
	%	42.4	52	5.4	0.2	100

In the table above, “number” denotes the number of observations for each combination of current speed and direction.

The data indicate that near-bed current speeds at the discharge site are below 0.2m/s for more than 90% of the time. For the year during which sampling was undertaken, maximum observed currents were less than 0.4m/s.

Reference 1 states that theoretically-derived spring tide current speeds at the site (from tidal harmonic constituents) are around 0.15m/s, but the basis for this statement is not known, nor whether this comment refers to peak speeds. However, this is consistent with the data observed, given that the currents at the site are likely to result from a combination of physical processes, including oceanic currents, storm surges, and tidal flows.

The currents at the discharge point appear not to have strong directional bias such as one would expect if tidal effects dominated the prevailing flows. However, there does appear to be a slight tendency for northeastward currents to dominate. This is confirmed by Table 3.4a of Reference 1 (not reproduced here) which presents the current data scatter.

2.1.2 Water depth

According to Reference 1, the water depth at the site is approximately 330m. At the nearest observation site to the discharge location, the mean spring and neap tidal ranges were found to be 3.1m and 1.4m respectively. These represent less than 1% change in total water depth through the tidal cycle, which can be ignored for the purposes of the discharge dispersion calculations.

2.2 DISCHARGE CHARACTERISTICS

2.2.1 Produced water characteristics

The parameters and constituent concentrations for the produced water discharge under normal operation are shown in Table 2.2. Discharge concentrations are as defined in the IPPC Licence granted in 2007 to Shell for discharge of produced water offshore of Erris Head. Background seawater concentrations, supplied by RSK, were derived from water quality monitoring undertaken in 2008 offshore of Erris Head. Under normal operating conditions the discharge will be positively-buoyant, that is, it will have a density lower than that of the ambient seawater.

Table 2.2 Normal operation discharge characteristics

Parameter	Unit	Background value	Discharge value
Maximum flow rate	m ³ /day	-	65
Specific gravity	-	1.03	0.92-0.95
pH	-	8	6-9
COD	mg/l	not given	400
Suspended solids	mg/l	3	5
Total Nitrogen	mg/l	0.15	10
Hydrocarbons (PAH, BTEX, TPH)	mg/l	0.0002	0.5
Phenol	mg/l	0.0002	0.001
Nickel	mg/l	0.0003	0.5
Zinc	mg/l	0.0004	0.5
Copper	mg/l	0.0002	0.05
Cadmium	mg/l	0.00004	0.005
Arsenic	mg/l	0.001	0.05
Mercury	mg/l	0.000001	0.0001
Lead	mg/l	0.0005	0.005
Chromium	mg/l	0.0005	0.1

2.2.2 Outfall configuration

Several design drawings for the outfall configuration were provided by Shell. It is understood that:

- Produced water will be pumped to the site in two separate cores of an umbilical, one 19mm diameter and the other 25.4mm diameter.
- At the release site, the cores will be bent upwards (but not necessarily exactly to the vertical), away from the umbilical.
- The produced water will leave the cores approximately 2m above the bed.
- It is not known how far apart the two cores will be at the point of release (for example, whether they will discharge directly next to each other).
- A fibreglass protection cover, approximate dimensions: 17m x 12m x 4m, may be placed on the bed at the site of the discharge, so that the pipes will discharge into the space between the protection cover and the manifold.
- The protection cover would have seven access apertures/windows (one fore, three port, three starboard), each with approximate dimensions: 1.5m x 1m.
- Therefore, whilst the discharge may initially be approximately vertical, the release into the open water outside any protection cover may in fact be lateral through the access apertures.

RSK requested that, at the present time, the effects of any protection cover on discharge dispersion should not be included in the calculations. For the purposes of modelling, a vertical discharge was assumed, into a range of ambient current speeds representative of the likely currents outside any protection cover. A single-outlet discharge was assumed (this is probably more conservative, in terms of dilution, than assuming that the discharges from the two cores occur separately). In order to ensure that the release was as “hydraulically similar” as possible to the actual discharge, it was assumed that the cross-sectional area of the discharge outlet was equal to the sum of the individual cross-sectional areas of the two umbilical cores (this gave a single discharge outlet diameter of 31.7mm). The resulting discharge exit velocity was around 1m/s, which is typical of the expected pipe exit velocities, but is likely to be very much larger than the velocities at which the diluted discharge would flow through the access apertures.

This approach will be discussed further in Chapter 4.

3. *Methodology*

Based on the natural hydrodynamic conditions at the site discussed in Chapter 2, an assessment of the likely dilution of the produced water discharge plume was made using the CORMIX expert system (Reference 2).

CORMIX is an internationally accepted software system for the analysis, prediction and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. It incorporates an expert system that uses the characteristics of the discharge (flow rate and configuration) and of the receiving water (depth, width, current speed, etc) to determine a class for the discharge jet. It then calculates the centre-line trajectory and dilution rate of the jet to the edge of the near-field area.

CORMIX also has some capability for estimating the mid- and far-field dispersion of the effluent, which has been utilised here. However, it must be appreciated that CORMIX cannot represent detail such as spatially varying bathymetry or current patterns; it provides approximations for uniform environments.

CORMIX has three sub-systems:

- CORMIX1, for submerged single-port diffuser discharges

- CORMIX2, for submerged multi-port diffuser discharges
- CORMIX3, for buoyant surface discharges.

As it had been decided (see above) to represent the release as a vertical point source, CORMIX1 was selected for the present modelling.

Data on the strength of the ambient currents in the vicinity of the site was selected from the information described in Chapter 2. CORMIX modelling was undertaken for ambient currents at the mid-points of the data bin ranges: 0.05m/s, 0.15m/s, 0.25m/s and 0.35m/s. As the currents closer to the bed are likely to be weaker than those higher up in the water column, the implications of this assumption will be discussed in Chapter 4. As the discharge is assumed to make an angle of 90° with the sea bed, the dilution of the discharge is independent of the direction of the ambient current.

The water depth at the site is around 330m, and varies by less than 1% during the tidal cycle. At such depths, mixing will not be significantly influenced by water level variations due to the tide or waves, and therefore an invariant water depth of 330m was assumed for the purposes of modelling.

The CORMIX predictions were used to estimate potential mixing zones for the following:

- To reduce constituent concentrations to 10% and 1% of their values at the release point
- To reduce constituent concentrations to within 10%, 5% and 1% of the ambient values.

4. Dispersion assessment

4.1 GENERAL BEHAVIOUR OF THE DISCHARGE PLUME

Discharge of the produced water vertically into an unbounded ambient environment results in the formation of a positively-buoyant plume. The turbulent plume rises from the release point entraining ambient seawater along its boundaries. The rise of the plume is at first due to its initial vertical momentum, but eventually, as momentum dissipates to the environment, the plume continues to rise under its own buoyancy. Predicted trajectories for the discharge plume are shown in Figures 4.1a, 4.1b, 4.1c and 4.1d for ambient current speeds of 0.05m/s, 0.15m/s, 0.25m/s and 0.35m/s respectively. For relatively strong ambient currents, the plume is more rapidly deflected to the horizontal than at lower current speeds, which results in a narrower and less diluted discharge.

4.2 MIXING ZONES

Table 4.1 shows the distances required to reduce concentrations of constituents in the discharge to 10% and 1% of their original values (that is, dilutions of 10:1 and 100:1 respectively). It can be seen that for the range of current speeds tested, dilutions of 100:1 are generally achieved within a 5m three-dimensional radius of the discharge point.

Table 4.1 Distance to minimum dilutions of 10:1 and 100:1, for different current speeds

Ambient Current speed (m/s)	Percentage occurrence	Distance (m) to minimum dilution			
		10:1		100:1	
		downstream	above bed	downstream	above bed
0.05	42.4	0.12	2.80	1.13	5.03
0.15	52	0.26	2.48	2.14	3.38
0.25	5.4	0.33	2.19	3.00	2.95
0.35	0.2	0.41	2.11	3.87	2.77

Tables 4.2a and 4.2b present the dilutions and distances required to reduce concentrations of constituents in the discharge to within 10%, 5% and 1% of the ambient seawater values. Clearly, for constituents whose discharge concentration is close to the seawater value (e.g. suspended solids), relatively small dilutions are required. For constituents at much larger concentrations than ambient (e.g. hydrocarbons, and certain metals), dilutions of several orders of magnitude are required.

In the modelling, settling of suspended substances has been neglected, as CORMIX cannot take this physical process into account. In terms of dilutions calculated within the water column, this is considered to be a conservative approach.

It can be seen that as current speeds increase, the required mixing zone lengths also increase. This is due to the increased level of deflection of the produced water discharge plume by the ambient currents, which results in a narrower and more concentrated plume. For the range of conditions assessed, predicted concentrations of each of the discharge constituents are reduced to within 10% of background values up to 300m downstream, to within 5% of background values up to 500m downstream, and to within 1% of background values up to 1600m downstream of the discharge location. It should be noted, however, that significantly smaller mixing zones are required for many of the discharge constituents.

Figure 4.2 also shows the variation in concentration of one of the discharge constituents, arsenic, with distance downstream for different ambient current speeds.

Table 4.2a Dilutions required to reduce discharge concentrations to within certain percentages of ambient seawater concentrations

Constituent	Units	Ambient value	Discharge value	Dilution required to reach percentage of ambient values		
				10%	5%	1%
pH		8	6-9	990	1980	9900
COD	mg/l	-	400	-	-	-
Suspended solids	mg/l	3	5	7	13	67
Total Nitrogen	mg/l	0.15	10	657	1313	6567
Hydrocarbons (PAH, BTEX, TPH)	mg/l	0.0002	0.5	24990	49980	249900
Phenol	mg/l	0.0002	0.001	40	80	400
Nickel	mg/l	0.0003	0.5	16657	33313	166567
Zinc	mg/l	0.0004	0.5	12490	24980	124900
Copper	mg/l	0.0002	0.05	2490	4980	24900
Cadmium	mg/l	0.00004	0.005	1240	2480	12400
Arsenic	mg/l	0.001	0.05	490	980	4900
Mercury	mg/l	0.000001	0.0001	990	1980	9900
Lead	mg/l	0.0005	0.005	90	180	900
Chromium	mg/l	0.0005	0.1	1990	3980	19900

Table 4.2b Distances required to reduce discharge concentrations to within certain percentages of ambient seawater concentrations

Constituent	Distance (m) required to reduce discharge concentrations to within certain percentages of ambient seawater values, for different ambient current speeds											
	10%				5%				1%			
	0.05 m/s	0.15 m/s	0.25 m/s	0.35 m/s	0.05 m/s	0.15 m/s	0.25 m/s	0.35 m/s	0.05 m/s	0.15 m/s	0.25 m/s	0.35 m/s
pH	6.6	13	18	24	11	21	31	41	34	71	105	137
COD	-	-	-	-	-	-	-	-	-	-	-	-
Suspended solids	0.1	0.2	0.2	0.3	0.2	0.4	0.5	0.6	0.8	1.5	2.1	2.7
Total Nitrogen	4.9	9.1	13	17	8.1	15	23	30	25	52	77	100
Hydrocarbons (PAH, BTEX, TPH)	66	143	213	277	109	242	361	469	392	820	1219	1582
Phenol	0.5	1.0	1.3	1.8	0.9	1.8	2.5	3.2	3.4	6.3	9.1	12
Nickel	49	105	157	204	81	178	266	345	261	602	898	1164
Zinc	40	85	126	164	66	143	213	277	207	485	722	937
Copper	13	25	37	48	21	42	62	82	66	143	213	277
Cadmium	7.8	15	22	28	13	25	37	48	40	84	125	163
Arsenic	3.9	7.3	11	14	6.5	12	18	24	21	42	62	81
Mercury	6.6	13	18	24	11	21	31	41	34	71	105	137
Lead	1.0	2.0	2.7	3.6	1.8	3.4	4.8	6.3	6.1	12	17	22
Chromium	11	21	31	41	18	35	53	69	56	121	180	234

4.3 DISCUSSION OF THE MODELLING SIMPLIFICATIONS

4.3.1 Ambient currents

Dispersion modelling was undertaken for representative ambient current speeds at the mid-points of the data bin ranges of the observed currents (taken from Reference 1). As stated in Chapter 2, currents were measured at 10m above the seabed, but Reference 1 takes the values as valid at 1m, without reduction, to allow a small margin of safety for

structural design/stability issues. Currents closer to the bed are likely to be weaker than those higher up in the water column, due to friction at the seabed.

The predictions above show that weaker ambient currents may result in shorter mixing zones, due to the resulting wider discharge plumes. Therefore, the actual mixing zones required, for an unbounded vertical discharge, are likely to be smaller than those presented above.

4.3.2 *Potential for build-up of the discharge*

The formulation of the CORMIX software assumes steady-state conditions and therefore the software cannot represent detail such as any build-up of discharge constituents which may occur near the outlet. Such build-up is usually associated with tidally-reversing environments, particularly where ambient currents are weak, which can result in partially-diluted effluent remaining in the vicinity of the discharge site. This can reduce the potential for initial dilution of a discharge. However, the analysis presented in Chapter 2 indicated that currents at the discharge point appear not to have significant directional bias such as one would expect if tidal effects dominated the prevailing flows. There does appear to be a slight tendency for northeastward currents to dominate, which would tend to carry the produced water away from the discharge point. The combination of these factors makes it unlikely that the discharge constituents would build up around the site, for a vertical unbounded discharge.

4.3.3 *Presence of a protection cover*

This study assumed that no protection cover would be in place at the discharge site. The effects of this assumption, if a cover was to be put in place, are considered here.

The way in which the discharge is introduced to the sea will be critical to its dilution following release. Factors such as the discharge orientation relative to the prevailing flows (inside or outside any protection cover), the effective cross-sectional area of the openings through which the discharge is introduced to the open waters, and the velocities of the discharge itself and of the seawater at the point of release, will all affect the way in which dilution of the discharge by ambient seawater initially takes place. The addition of a protection cover would transform the above relatively simple open-ended pipe discharge scenario into a more complex situation, to which the methods presented in this study are not fully appropriate.

Detailed analysis of potential flow patterns within a protection cover is beyond the scope of the present study. However, it is likely that flows inside a protection cover, which would interact with the discharge at its point of release, would be relatively complex, and would be different to the prevailing ambient currents at the site outside a protection cover.

As modelling has been undertaken for the produced water as a point release discharging vertically, into an unbounded environment, the model predictions are likely to be different to the actual behaviour when the discharge arrangements are implemented if a protection cover is used.

In view of the above, whilst it is not possible to make recommendations as to whether options for positioning the discharge outside a protection cover should be considered, it can be said that the modelling tools used for this study would be likely to predict the

discharge's dilution more accurately for a discharge outside a protection cover than for a discharge inside a cover.

Initial tests carried out for unbounded discharges of both neutrally-buoyant and positively-buoyant produced water indicate that buoyant effluent is likely to mix and dilute more readily than a discharge with neutral buoyancy, due to the additional entrainment that occurs during the rising phase of the plume. Therefore, the confinement of the discharge within a protection cover, which is likely to inhibit the rise of the plume, may place a significant restriction on the potential dilution. Assessment of the potential reduction in dilution is beyond the capabilities of the current modelling approach.

Depending on the exact structure of any protection cover, produced water may build up underneath the lid before emerging from the side apertures. The effects of this on dilution cannot be accurately determined as part of the present analysis. Whilst the discharge might be introduced into the open water over a wider area (due to the division between the different apertures, which may afford extra dilution to the discharge), there may also be a decrease in dilution due to the reduction of momentum-induced jet mixing.

5. *Conclusions and recommendations*

An assessment of the dispersion of produced water from a proposed release point at Corrib has been undertaken. The results of mixing zone modelling indicate that, for the range of conditions assessed, predicted concentrations of each of the discharge constituents can be reduced to within 10% of background values up to 300m downstream, to within 5% of background values up to 500m downstream, and to within 1% of background values up to 1600m downstream of the discharge location. It should be noted, however, that for many of the discharge constituents, significantly smaller mixing zones are required to reduce concentrations to values approaching background concentrations.

The results of the present modelling have been obtained assuming that the produced water is discharged vertically into an unbounded seawater environment, and it should be considered when using the results in this report that dilution rates may vary if the discharge is located under a protection cover.

6. *References*

1. Corrib Field Development – Metocean Criteria Corrib Field and Sealine Route, Metoc Report No. 978, October 2000
2. Doneker, R. L., and Jirka, G. H. (2007), "CORMIX User Manual. A hydrodynamic mixing zone model and decision support system for pollutant discharges into surface water.", Office of Science and Technology, U.S. Environmental Protection Agency, Washington, DC 20460

Figures

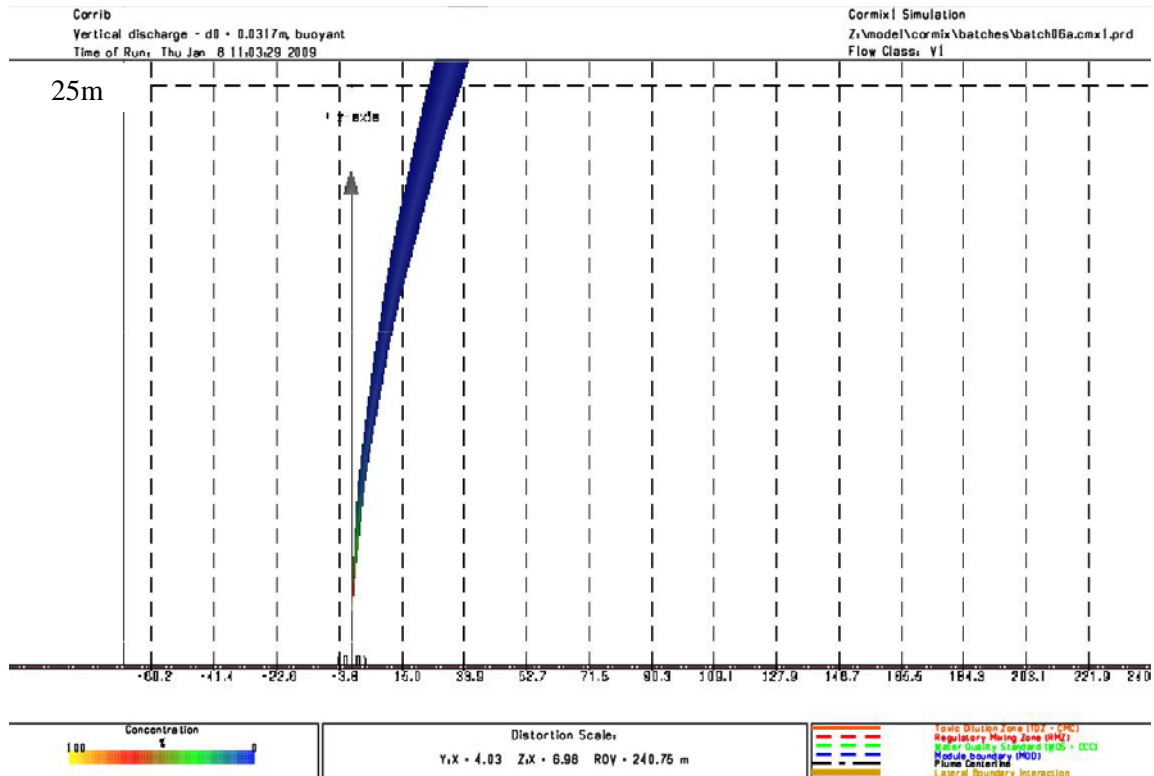


Figure 4.1a Predicted trajectory for ambient current speed of 0.05m/s

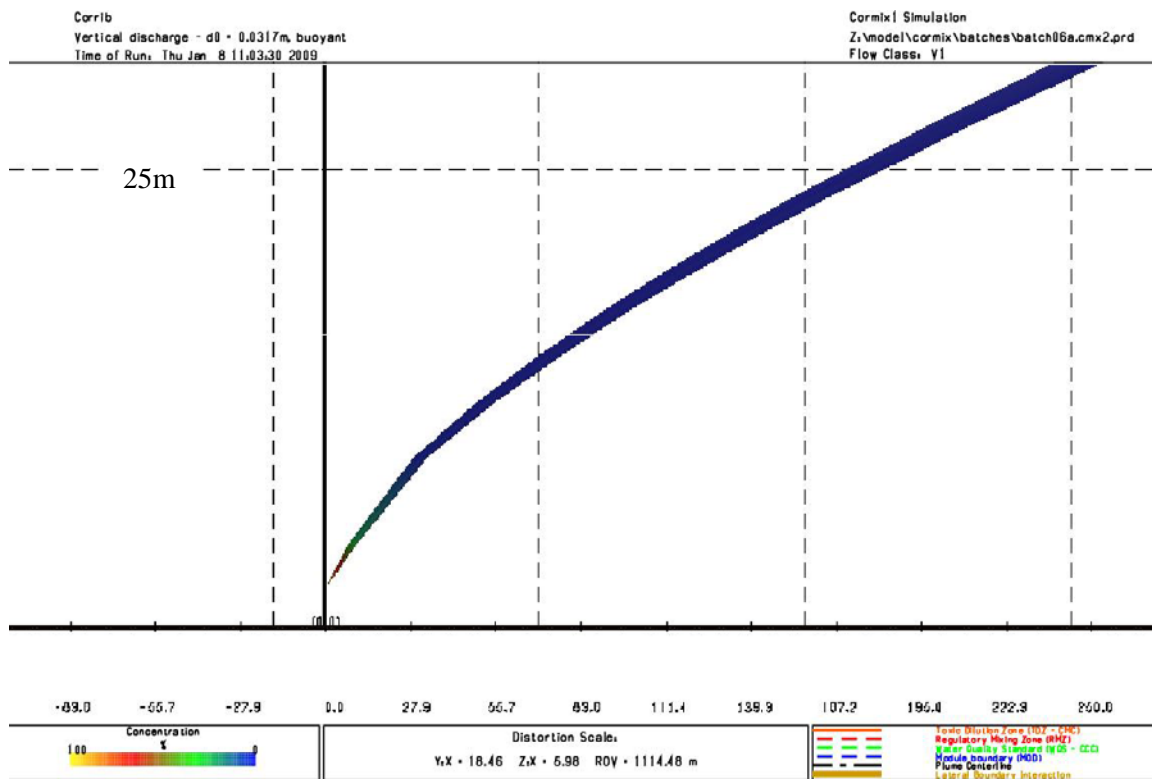


Figure 4.1b Predicted trajectory for ambient current speed of 0.15m/s

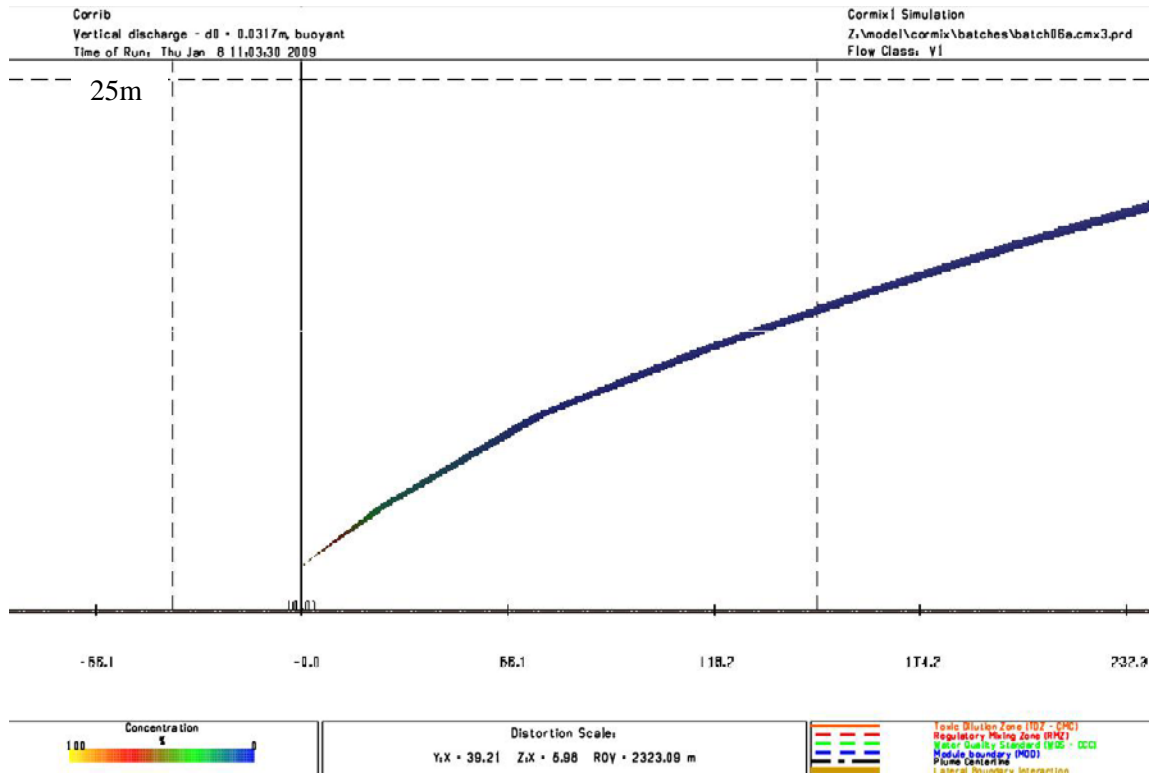


Figure 4.1c Predicted trajectory for ambient current speed of 0.25m/s

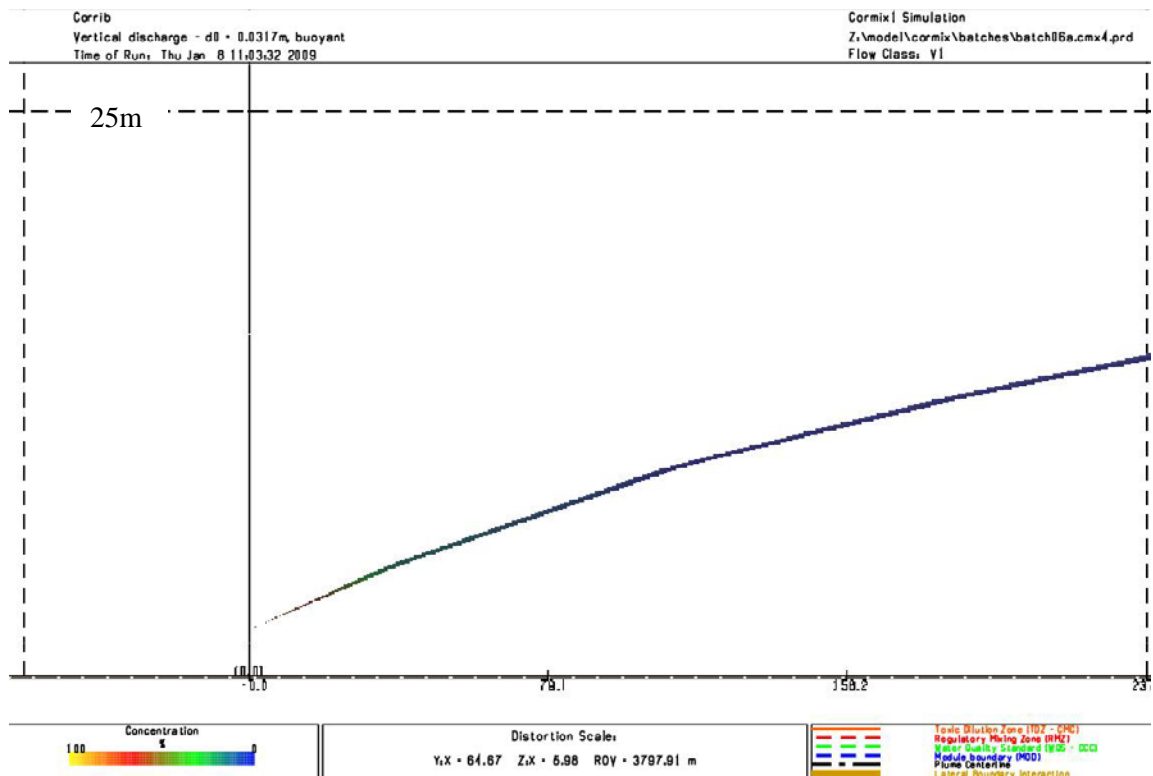


Figure 4.1d Predicted trajectory for ambient current speed of 0.35m/s

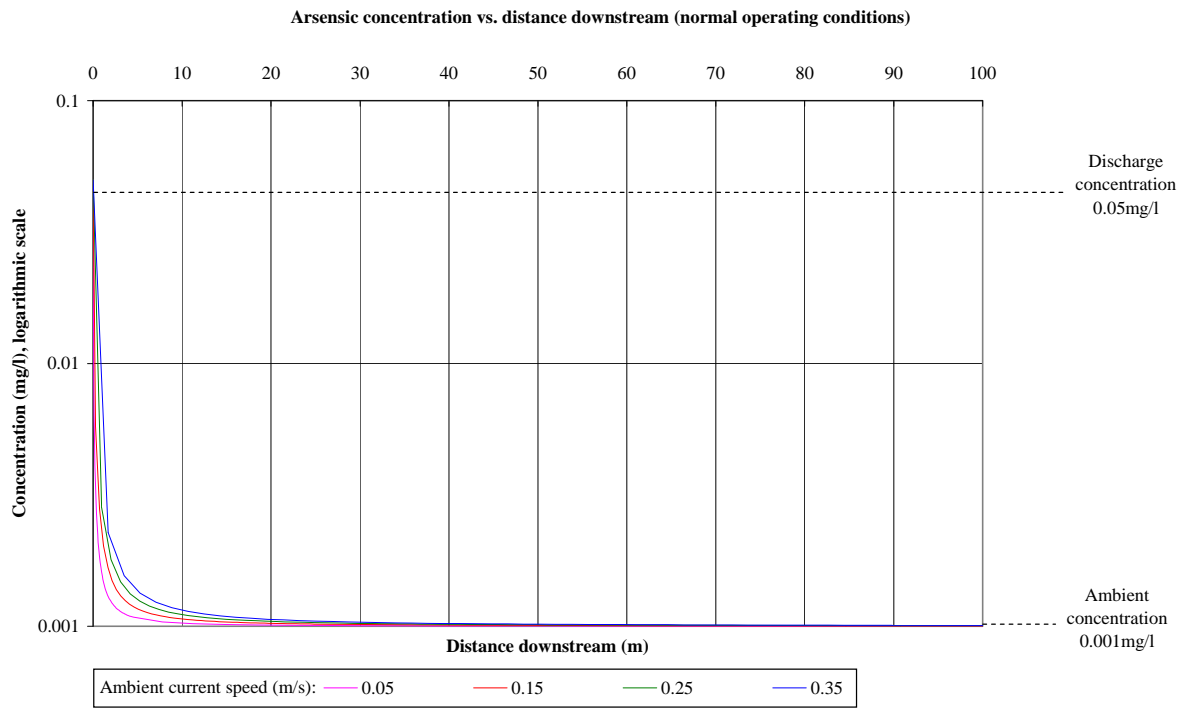


Figure 4.2 Variation of arsenic concentration with distance downstream