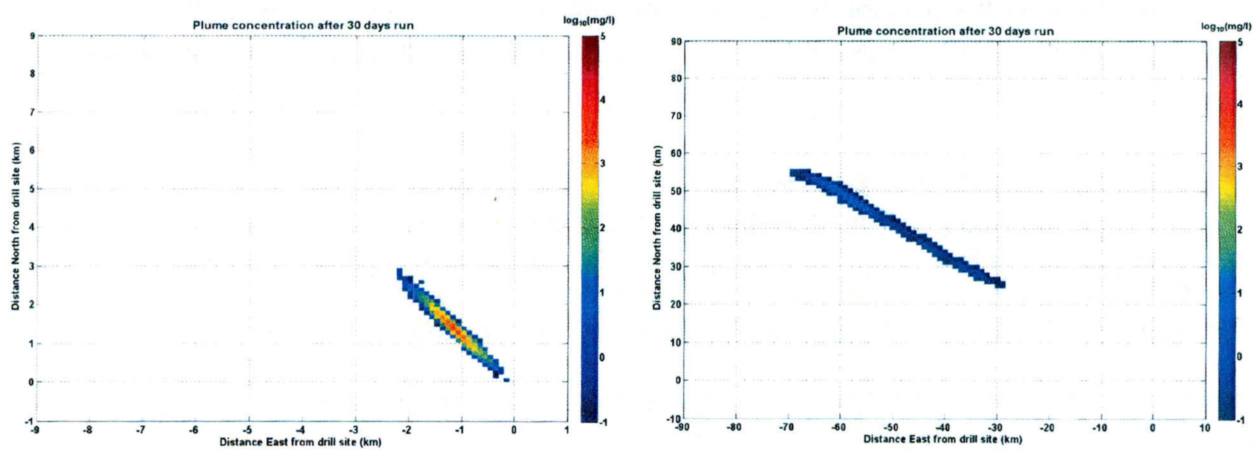
depth. The largest horizontal width at the end of the cloud collapse phase was found in the winter scenarios (210 m), and the smallest in the summer scenarios (170 m). The maximum horizontal extent of the outer edge of the collapsed cloud (425 m from origin) was reached in the winter scenarios. The different tidal scenarios showed that the clouds generally travelled to the southeast (ebb tide) and to the northwest (flood tide) of the point of release, with the excursions being larger during the spring tides than during neap tides.

At the end of the cloud collapse phase, the behaviour of the WBM sediment clouds is no longer governed by the dynamics of the release, and they are expected to be subjected to further dispersion by the ambient residual and tidal currents. The sediment concentrations at the cloud centres at the end of each phase indicate that minimum dilution factors between 20 and 30 were achieved within half an hour from release time, and minimum dilution factors between 60 and 80 were achieved within one hour from release time for all scenarios. The reduced concentration of both the barite and clay results in further reduced settling velocities. Therefore, they are expected to reach the bottom boundary layer within a period on the order of days.

Long-term Deposition

For the high settling velocity scenario, the final plume size is on the order of 2 to 3 km long and less than 1 km wide. Also, because of this high settling value and low currents on the order of a few cm/s, all the material stays within the first metre of the water column (Figure 2.8). Concentrations are in the range between 250 mg/l and 1 g/l. The highest concentration occurs at the centre of the plume, two to three orders of magnitude higher than at the margins. Overall, the averaged plume concentration time-series shows a stabilization of the concentration near approximately 250 mg/l after approximately 20 to 25 days of the 30 day modelling exercise.



Winter = High settling velocity; Summer = Low settling velocity.
Source: AMEC 2011

Figure 2.8 Greatest Extent of Drill Cuttings Deposition Modelling in Winter Season (left) and Summer Season (right)

2.12.1.3 Summary of Modelling Results

Information in this section is from AMEC (2011), which should be reviewed for more detail on the dill cuttings deposition model. Drilling operations will result in:

- sea floor discharge of 196 m^3 of cuttings;
- surface discharge of 211 m^3 of cuttings;
- sea floor discharge of 1,210 m^3 of WBM of various density and composition; and
- surface discharge of 400 m^3 of WBM combined with 50 m^3 of brine.

Sea floor discharge of cuttings is expected to result in a mound extending approximately 30 m from the well site, with cuttings thicknesses greatest immediately adjacent the well site. Average thickness is approximately 22 cm out to approximately 20 m from the well site; maximum thickness is approximately 4.7 m. From 20 to 50 m out from the well site, the average thickness is less than 1 mm.

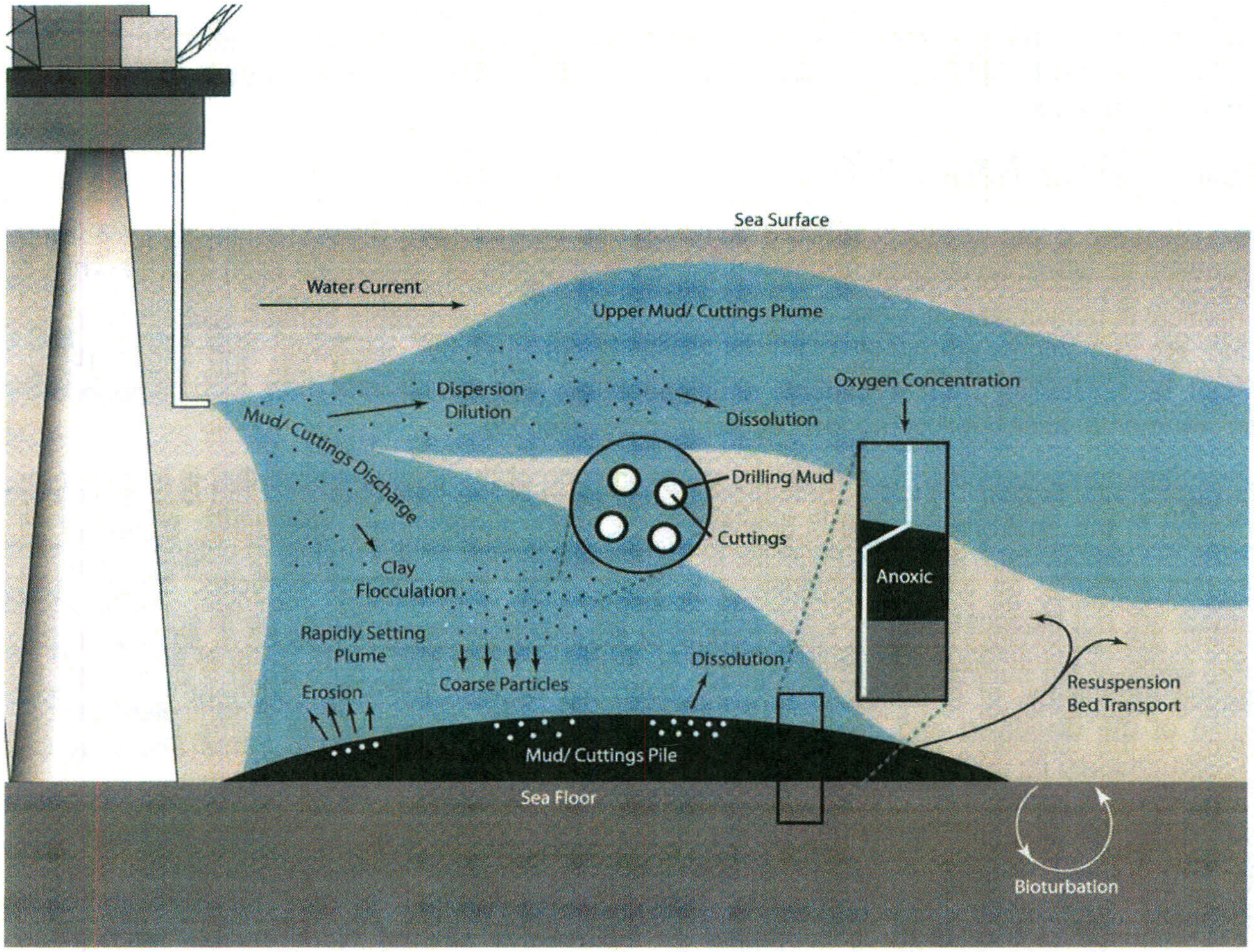
Surface release of cuttings is expected to produce a deposit with thickness greatest near the drill origin, due to the most rapid fall of the heavier pebble and sand cuttings particles, and is as thick as 15 mm directly below the point of origin. Out to approximately 100 m from the origin, thicknesses are approximately 2 mm on average with a maximum of approximately 6 mm. From 100 to 200 m, thicknesses average from approximately 0.5 to 1 mm, with a maximum of approximately 6 mm.

If cuttings released from the rig are associated with SBM, maximum synthetic-based oil concentration within 50 m from the point of discharge is predicted to be approximately 25 percent of that of the original treated and released cuttings, or 17,000 mg/kg. Within 100 m, the concentration drops another factor of seven, to approximately 2,400 mg/kg. Outside of 200 m, the concentration is 44 mg/kg or less. Outside of 500 m, this concentration is 3 mg/kg or less.

The surface bulk release of WBM at the end of the well is expected to result in a plume reaching a depth of approximately 150 m, thereby not reaching the bottom. Dilutions of 20 to 30 times the original concentration are expected within 30 minutes from discharge and dilutions of 60 to 80 times are expected within 60 minutes of discharge. Subsequently, material in the plume is expected to sink slowly and eventually reach the bottom boundary layer after several days.

Simulation of the long-term fate of all the mud released over the entire drilling program considered the conservative scenario where there is no interruption between each phase of drilling operations, in which case, all the mud would be released over a period of 15 days.

Results show that dispersion of the mud by the ambient tidal and mean currents result in an elongated plume varying from 2 to 3 km to approximately 40 km in length, depending on settling velocity, with widths from less than one to a few (numbers) kilometres, respectively. This variability is typical of the range of behaviour of drilling mud, and is consistent overall with other similar studies.



Source: Neff 2005.

Figure 7.4 Dispersion and Fate of Water-based Drilling Mud following Discharge

Based on modelling results (AMEC 2011), drilling operations will result in:

- sea floor discharge of 196 m^3 of cuttings;
- surface discharge of 211 m^3 of cuttings;
- sea floor discharge of 1,210 m^3 of WBM of various density and composition; and
- surface discharge of 400 m^3 of WBM combined with 50 m^3 of brine.

Sea floor discharge of cuttings is expected to result in a mound extending approximately 30 m from the well site, with cuttings thicknesses greatest immediately adjacent the well site. Average thickness is approximately 22 cm out to approximately 20 m from the well site; maximum thickness is approximately 4.7 m. From 20 to 50 m out from the well site, the average thickness is less than 1 mm.

Surface release of cuttings is expected to produce a deposit with thickness greatest near the drill origin, due to the most rapid fall of the heavier pebble and sand cuttings particles, and is as thick as 15 mm directly below the point of origin. Out to approximately 100 m from the origin, thicknesses are approximately 2 mm on average with a maximum of approximately 6 mm. From 100 to 200 m, thicknesses average from approximately 0.5 to 1 mm, with a maximum of approximately 6 mm.

Bioavailability and Accessibility

Bioavailability is the extent to which a chemical can be absorbed (bioaccumulated) by a living organism by active (biological) or passive (physical or chemical) processes (Neff 2002a). Thus a chemical is bioavailable if it can move through or bind to a permeable surface coating (such as skin, gill epithelium, gut lining, cell membrane) of an organism (Newman and Jagoe 1994). Metal bioavailability from sediments (cuttings piles) can be divided into two components: environmental accessibility and environmental bioavailability.

Environmental accessibility is a measure of the fraction of the total chemical that is in a form or location in the environment that is accessible for bioaccumulation by organisms. Metals of all forms in cuttings have a low accessibility to marine organisms as the metals in cuttings piles are present primarily as insoluble inclusions in barite, clay, and cuttings particles. These solid metals are not bioaccessible. A small portion of the metal component may be in solution in the pore water of the cuttings pile (Shimmield et al. 2000). If the cuttings pore water is accessible to marine organisms, or is mixed up into the overlying water column by sediment disturbance, some of the dissolved and colloidal metals in it may be in bioavailable forms and may be bioaccumulated by marine organisms (Neff 2005).

Environmental bioavailability is dependent on the interactions between a marine organism and its environment. Exposure occurs at the interface between environmental media (water, sediment, and food) and permeable biological membranes of the marine organism. Environmental bioavailability is controlled by the relative amount of permeable epithelia in contact with the environmental media, the duration of contact, and the physical form of the chemical in the environmental medium. Dissolved, free ionic forms, some metal-organic colloid complexes, and low molecular weight organo-metal compounds of metals are the most bioavailable forms of most metals to marine organisms (Neff 2002). The most bioavailable fraction of metals associated with WBM and cuttings is that dissolved in the pore water or loosely complexed with particles. The majority of metals associated with WBMs and cuttings are associated with sulphide mineral inclusions in the barite and are not soluble in anoxic marine sediment pore waters (Trefry et al. 1986; Neff 2002). The distribution of metals in different geochemical fractions of North Sea cuttings pile sediments found that approximately 17 percent of the lead and 36 percent of the nickel in North Sea cuttings piles are in potentially bioavailable forms (Westerlund et al. 2001, 2002).

Barium and Chromium

The most abundant metal in most WBM is barium. Nearly all the barium in drilling mud is from barite ($BaSO_4$) added to the mud to increase its density (Neff 2005). Using barium as a tracer, the zone of detection for both single and multiple wells found that background levels for barium were achieved at 1,000 to 3,000 m from the drill source. Barite in drilling muds and sediments has a low solubility in seawater (because of the high natural concentration of sulfate in the ocean), and because it is insoluble in seawater, it has a low bioavailability and toxicity to marine