4 Results

4.1 Suspended Sediment Concentrations

Simulations indicated that sediments suspended by discharging from the conduits would tend to drift southwards from the Flacourt Bay site and northwards from the North White's Beach site (Figure 2 and 3), reflecting the strong influence of tidal currents on local hydrodynamic flows. Analysis of the vertical and horizontal distributions of discharged material by particle-class indicated that coarser cuttings material will tend to settle locally (< 1 km) to the discharge sites, but clay (contributed by bentonite) and fine silt (generated by rock drilling) would remain suspended in the lower water column for extended periods of time (days). Current speeds are predicted to be too high to allow faster settlement of these fine particles.

If bentonite is discharged from Flacourt Bay, elevated levels (> 1 mg/l above background) of suspended sediments are expected to potentially extend beyond Boodie Island at times. Locations as far south as Middle Island are expected to experience instantaneous concentrations > 25 mg/l. There were relatively minor differences in the potential zone of influence predicted from simulations using currents predicted for June through to December, indicating that the tidal currents predominate. Onshore winds typical of summer tended to result in material drifting closer to the coast compared to winter, when offshore winds are more common. Instantaneous concentrations of bentonite at > 250 mg/l where predicted to occur up to 8 km south of the Flacourt Bay discharge site at any time from winter to summer. Biggada Reef was predicted to experience instantaneous concentrations exceeding 300 mg/l during all simulations of discharge from this site.

Simulations of bentonite discharge from the North White's Beach site indicated that elevated concentrations of bentonite (at up to 150 mg/l) would consistently occur around the North end of Barrow Island. Bentonite particles were predicted to migrate northwards and to become trapped within the strong tidal currents that operate in this area, although some bentonite is also expected to drift southward along the coast under winter conditions. Figure 4 shows predictions for the plume that could be generated by discharge at North White's Beach at hourly steps. Results show that material is likely to be transported clockwise around the northern end of Barrow Island on a flooding tide, but will tend to migrate directly westward on an ebbing tide. Consequently, sediments are not expected to migrate back towards the discharge site. Reversal of the strong tidal flows around the north end of the Barrow Island were also predicted to result in a concentration of the suspended plume at the change of each tide (e.g. see steps C to D in Figure 4).

Analysis of the time-varying concentrations expected over given locations (Figures 5-8) indicated that movement of the plume is likely to result in repeated episodes of relatively short-term exposure, rather than chronic exposure. Typical return periods between exposure to elevated concentrations varied from location to location and with the discharge site. In general, locations along the west coast are expected to have shorter return periods (i.e. more chronic exposure) because tidal migrations are shorter along this coast. In contrast, locations off the north-east coast of Barrow Island are only expected to experience elevated concentrations twice per day at the top of each tide (i.e. at the end of each flood).

Table 3 lists the criteria that were specified by RPS-BBG as indicative of impacts of sedimentation and suspended sediment on corals, based on a review of the available literature. The criteria for suspended sediments relate to impacts through suppression of light levels and thus consider exposure during daylight hours only. Based on these criteria, discharge of bentonite at North White's Beach would be expected to cause total mortality only to corals in the immediate vicinity (within < 200 m) of the discharge. Partial mortality would be expected over a 3 km long strip extending south of the discharge and the zone of influence would extend from approximately 4 km south of the discharge to the north-east corner of Barrow Island (Figure 9).

Table 3: Criteria Used to Judge the Significance of Suspended Sediment Concentrations

Effect	Time frame	Concentration	Rate of occurrence	Consecutive days
Total coral mortality	Short	$\geq$25 mg l^{-1}	> 6 hours per daylight period*	5
Partial coral mortality	Short	$\geq$25 mg l^{-1}	> 6 hours per daylight period*	2
Zone of Influence (no mortality)	Short	$\geq$1 mg l^{-1}	> 1 hour at any time	1

* 6 am to 6 pm

It should be noted that bentonite may cause other impacts beyond reduction of light levels, such as interference with feeding or smothering of polyps, and thus the threshold concentrations and consideration of day-time exposure only may not be appropriate to judge potential impacts on corals. The time-series results showing expected changes in suspended solid concentrations over time (e.g. Figures 6 and 8) would be more appropriate in this case.

Discharge simulations assuming that cuttings are released with a water-based polymer indicated a much reduced zone of potential influence by suspended sediments in comparison to the bentonite case (Figures 10 and 11). Suspended solid concentrations were not expected to exceed 25 mg/l beyond the immediate location of each discharge and concentrations > 1 mg/l suspended sediments were only expected to occur within 2-3 km. Plumes with > 1 mg/l were predicted to only cover an average area of 0.05 km^2 at any given point in time (compared to 5 km^2 with bentonite). Similarly, concentrations of suspended sediments expected over time at any location were two orders of magnitude lower where bentonite was not discharged. This effect is illustrated in Figure 11 for a location on Biggada Reef, given discharge at Flacourt Bay under identical conditions with and without bentonite. Based on the criteria given in Table 3, partial or total coral mortality would not be expected for any location beyond the immediate discharge.

Suspended sediment concentrations quoted here were based on multiple simulations under different conditions and assumed that there were no background concentrations of suspended sediments generated by previous discharges. Tests for overlap between simulations, by running simulations for up to 15 days beyond the end of discharge indicated that some bentonite could still remain suspended within the study area after 7-10 days, but cuttings sediments were not expected to remain suspended for more than five days. These results indicate the potential for compounding of the suspended sediment concentrations for bentonite from one discharge to the next. It should also be noted that modelling assumed that sediments did not resuspend after settling. However, as the west coast of Barrow Island is subject to wave action, there is also the potential for compounding of the suspended sediment loads by fine sediments that have been resuspended by wave action. Studies by Environment Canada indicate that bentonite can be readily resuspended into the benthic layer by wave action, but the material then sinks when waves dissipate (Milligan *et. al*. 1996).

4.2 Sedimentation

Calculation of cumulative sedimentation, based on combining the sedimentation resulting from each of the ten independent discharges for each combination of site and discharge type and assuming that there is no resuspension and redistribution of sediments between each period of discharge, indicated that a significantly larger area of seabed would be impacted if bentonite was used as the drilling fluid (Figure 12 to 15). Bentonite discharged at Flacourt Bay was predicted to settle along the full extent of the Barrow Island coast from Boodie Island to the north-eastern corner of Barrow Island (Figure 12). Concentrations within Flacourt Bay were predicted to exceed 12 kg/m^2 near the discharge and concentrations > 1 kg/m^2 are expected to extend up to 3 km to the north and south of the discharge site. Concentrations > 10 kg/m^2 are predicted to accumulate on Biggada Reef. In contrast, a much reduced sediment pile was predicted for discharge of cuttings with polymer (Figure 13). Concentrations were predicted to peak at approximately 500 g/m^2 around the discharge and at < 150 g/m^2 on Biggada Reef.

Discharge from North White's Beach is expected to result in sedimentation over the tidal channel around the north end of Barrow Island (Figure 14). A more even spread of sediments with lower peak concentrations were predicted for discharge at this site due to the higher current speeds to the north. Peak concentrations were predicted to occur on the reefs and channel edges along the tidal path. Discharge with bentonite was predicted to result in peak concentrations at up to 10 kg/m^2 adjacent to the discharge point and up to 5 kg/m^2 on some of the reefs. In contrast, discharge with polymer is expected to generate peak sedimentation of < 250 g/m^2 at the discharge point and < 100 g/m^2 on reefs along the tidal path (Figure 15).

Results indicate that a continuous layer of sediments would be expected on the seabed within an elliptical area surrounding the discharges. The area was predicted to be considerably larger for bentonite discharge compared to polymer-based discharge. As stated, these results assume no re-suspension of sediments. If resuspension is an important process, then resuspended sediments would be subject to the tidally-dominated currents acting over the study area and thus, over the shorter-term, would be expected to redistribute within the same area of effect predicted for first settlement. Consequently, resuspension is likely to result in a more even distribution of sediments rather than an increase in the field of effect. Thus, results presented here would tend to overestimate the near-field concentrations but under-estimate the far-field concentrations.

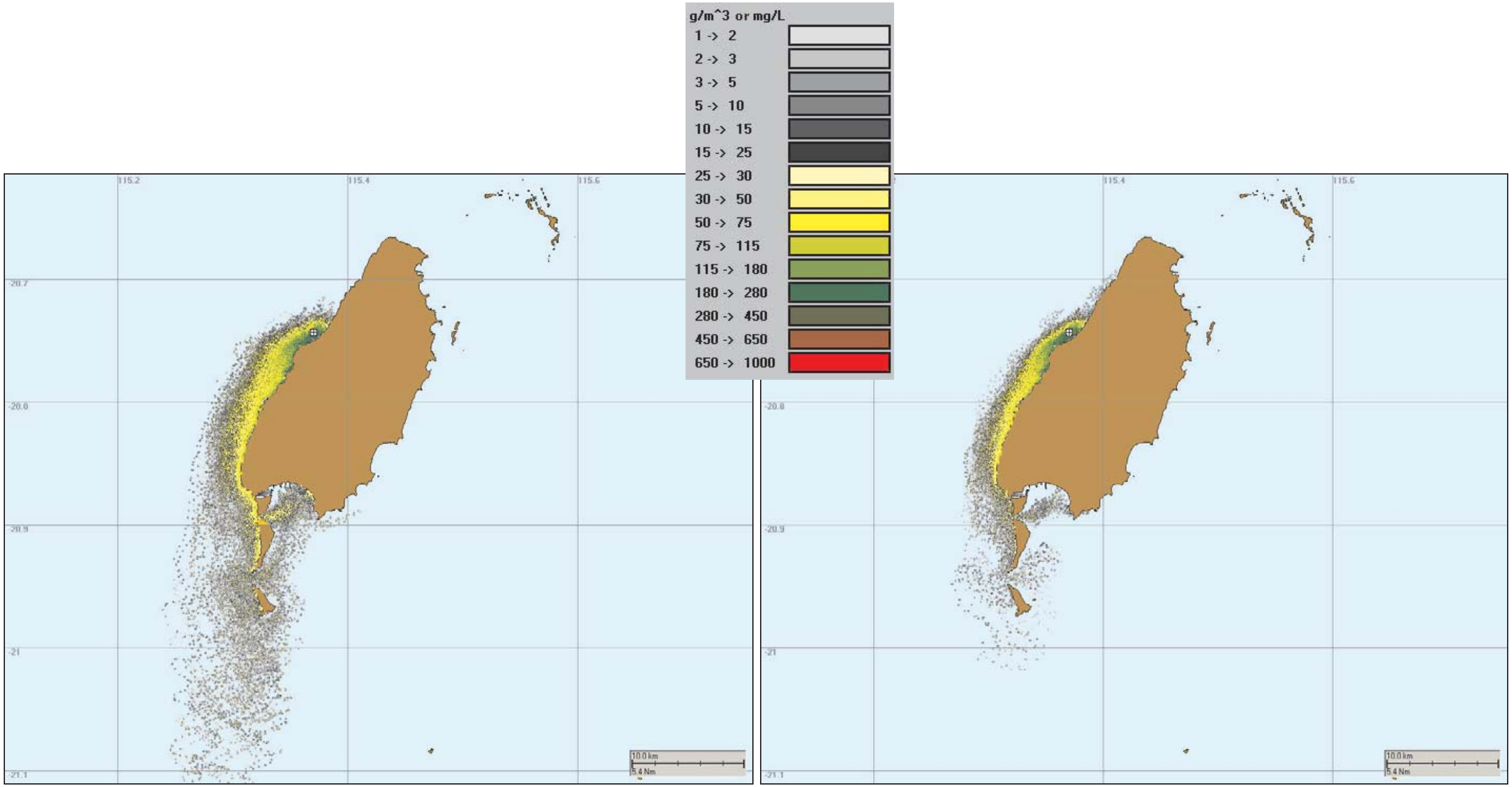

Figure 2: Examples of the zone of influence and maximum instantaneous concentrations of suspended solids predicted for individual locations as a result of discharges of bentonite and cuttings off Flacourt Bay under different environmental conditions. Each figure shows the outcome from 10 days of discharge given a different 10-day sample of currents. Left figure is from June, right figure is from December. Note: the collective areas do not represent the plume at any one point in time (see Figure 4 for clarification).

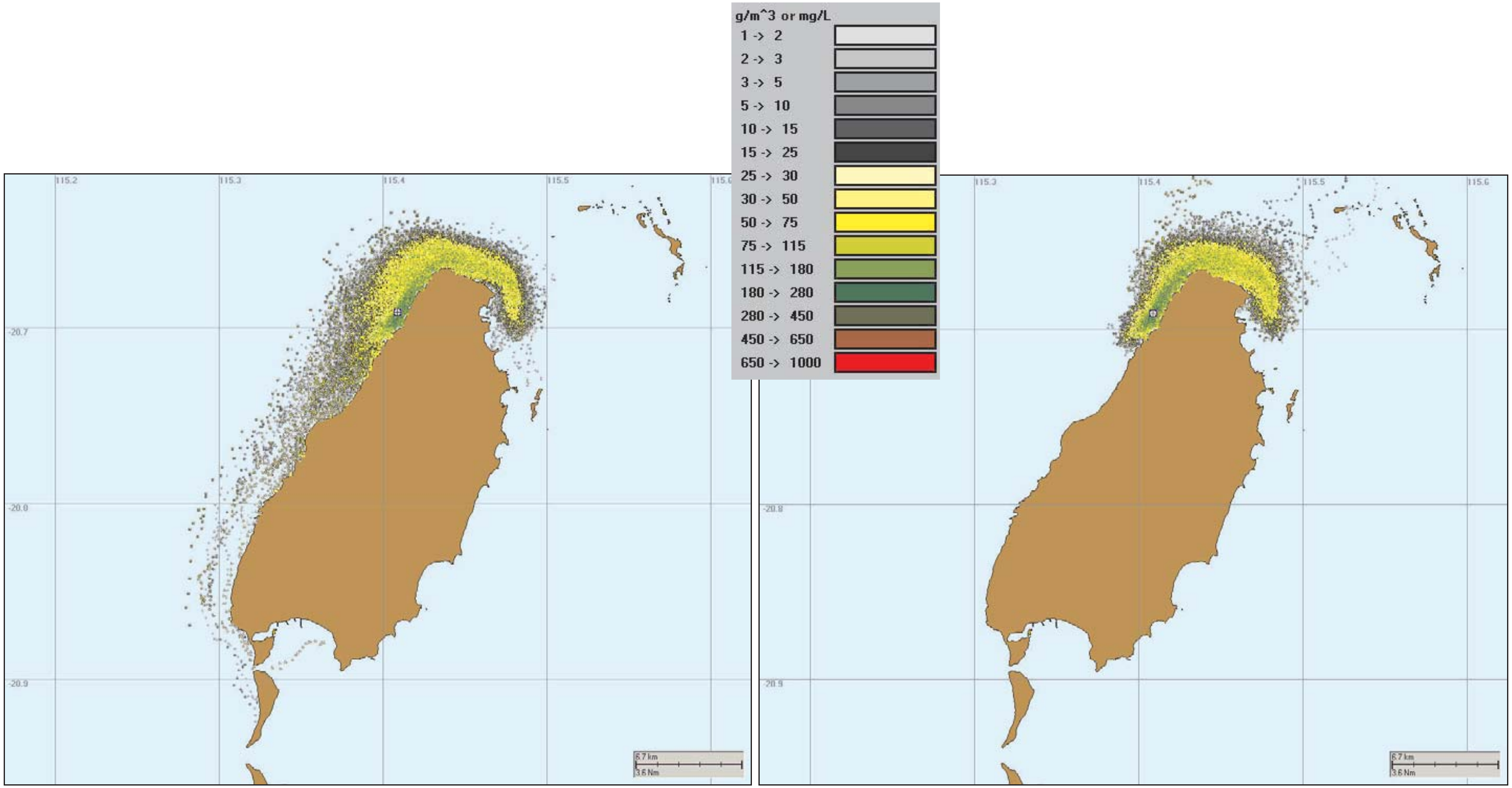

Figure 3: Examples of the zone of influence and maximum instantaneous concentrations of suspended solids predicted for individual locations as a result of discharges of bentonite and cuttings off North White's Beach under different environmental conditions. Each figure shows the outcome from 10 days of discharge given a different 10-day sample of currents. Left figure is from June, right figure is from December. Note: the collective area does not represent the plume at any one point in time (see Figure 4 for clarification).

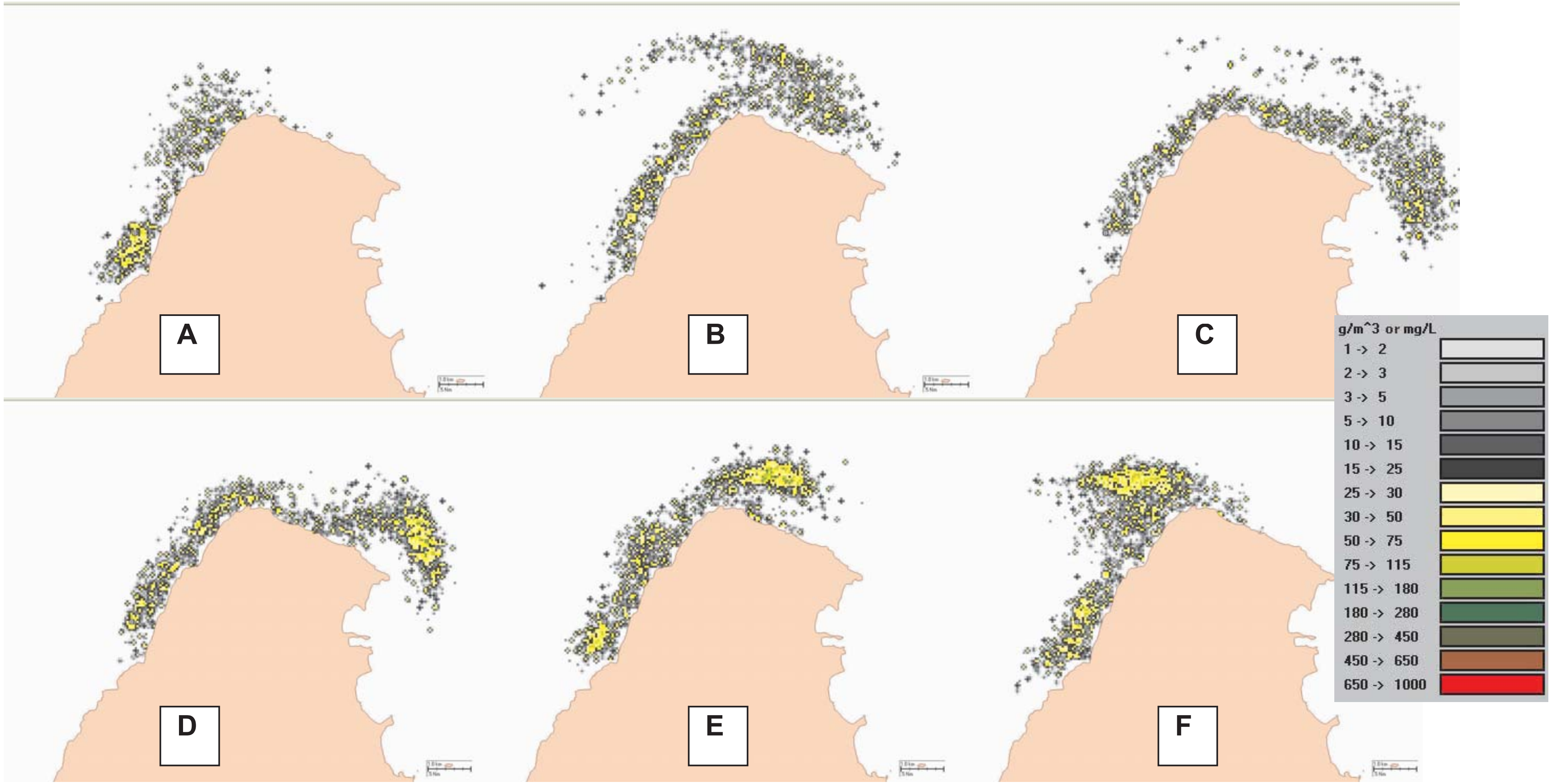

Figure 4: Example of the evolution of a sediment plume expected with changing tidal states during bentonite discharge at North White's Beach. The examples are for one set of conditions. Plumes are shown commencing at the end of one ebb tide and concluding at the end of the next ebb tide. Note that an accumulation of sediments is expected to occur at the turning of the tide.

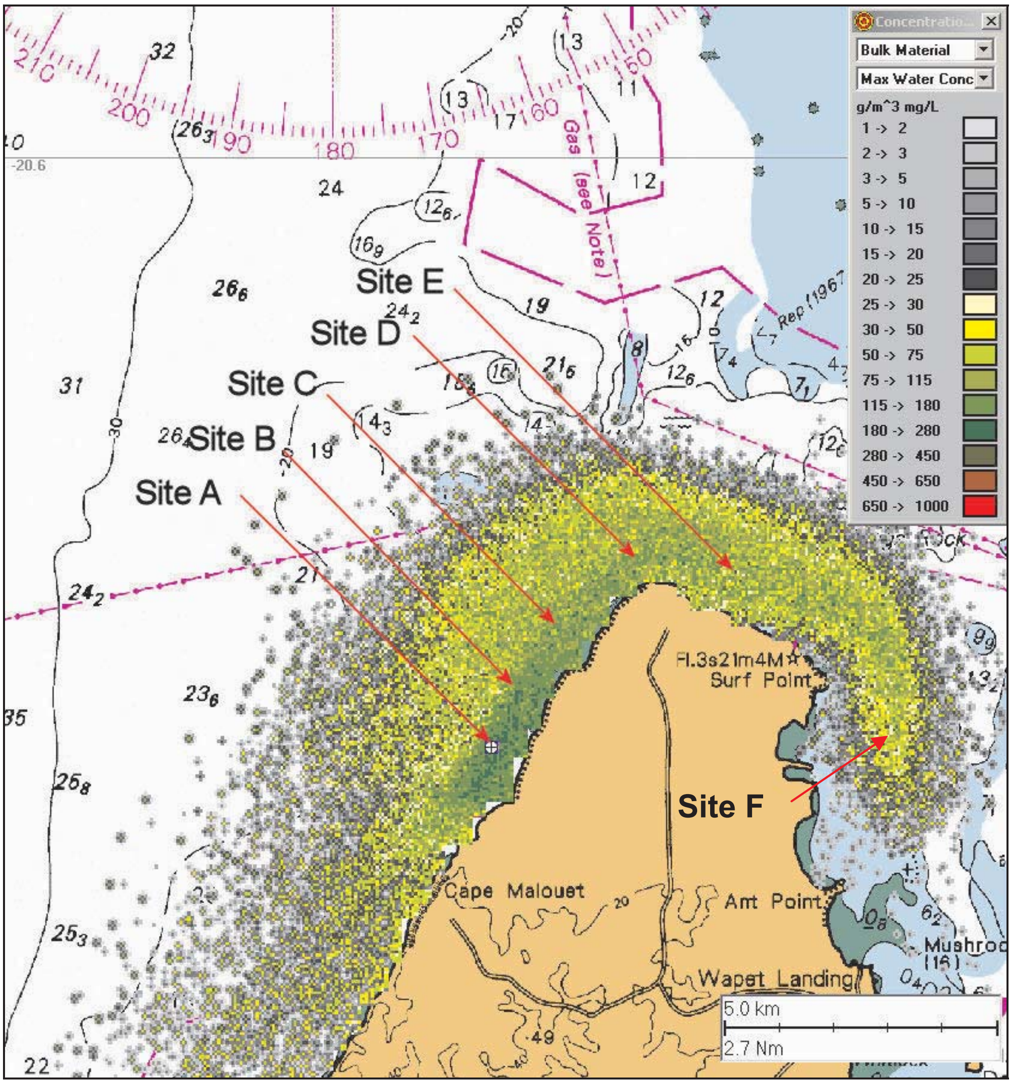

Figure 5: Maximum instantaneous concentrations of suspended solids predicted for locations surrounding the North White's Beach discharge site (shown by the white marker), given a 5 day discharge of bentonite and cuttings (simulation period of 8 days). Site markers relate to details shown in Figure 6.

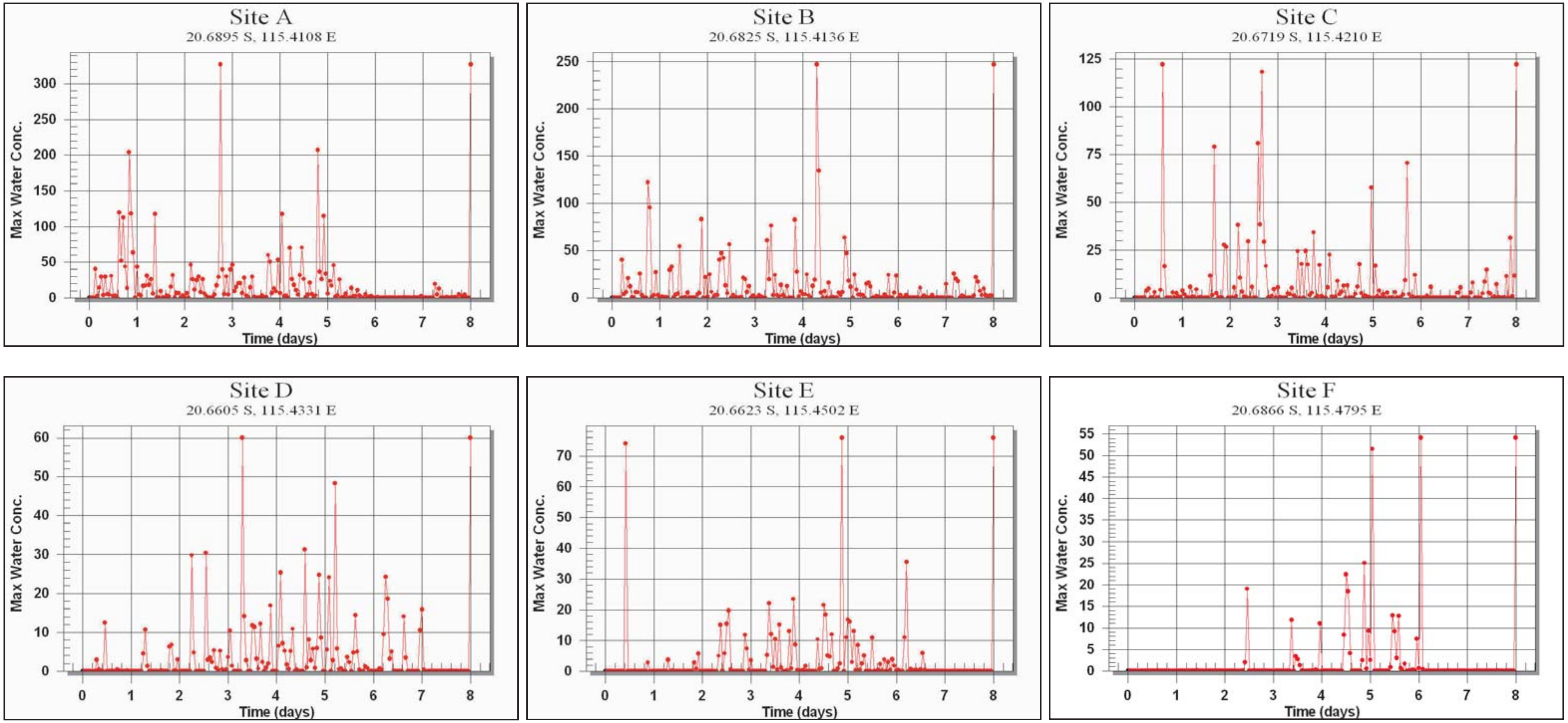

Figure 6: Time-varying concentrations of suspended sediments predicted for locations indicated in Figure. Note (1) the scale of the vertical axis varies among plots to highlight variations at each site (2) the point shown at last time step is the maximum value during the period.

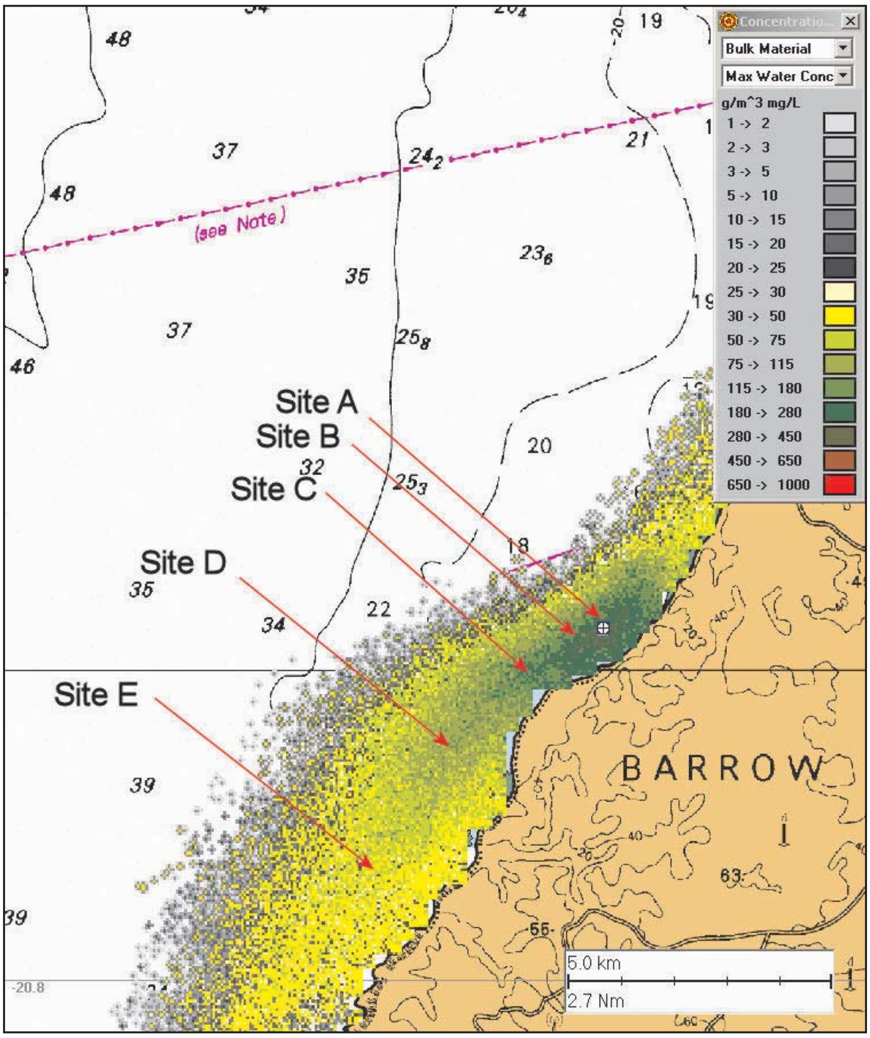

Figure 7: Maximum instantaneous concentrations of suspended solids predicted for locations surrounding the Flacourt Bay discharge site (shown by the white marker), given a 10 day discharge of bentonite and cuttings (simulation period of 8 days). Site markers relate to details shown in Figure 8.

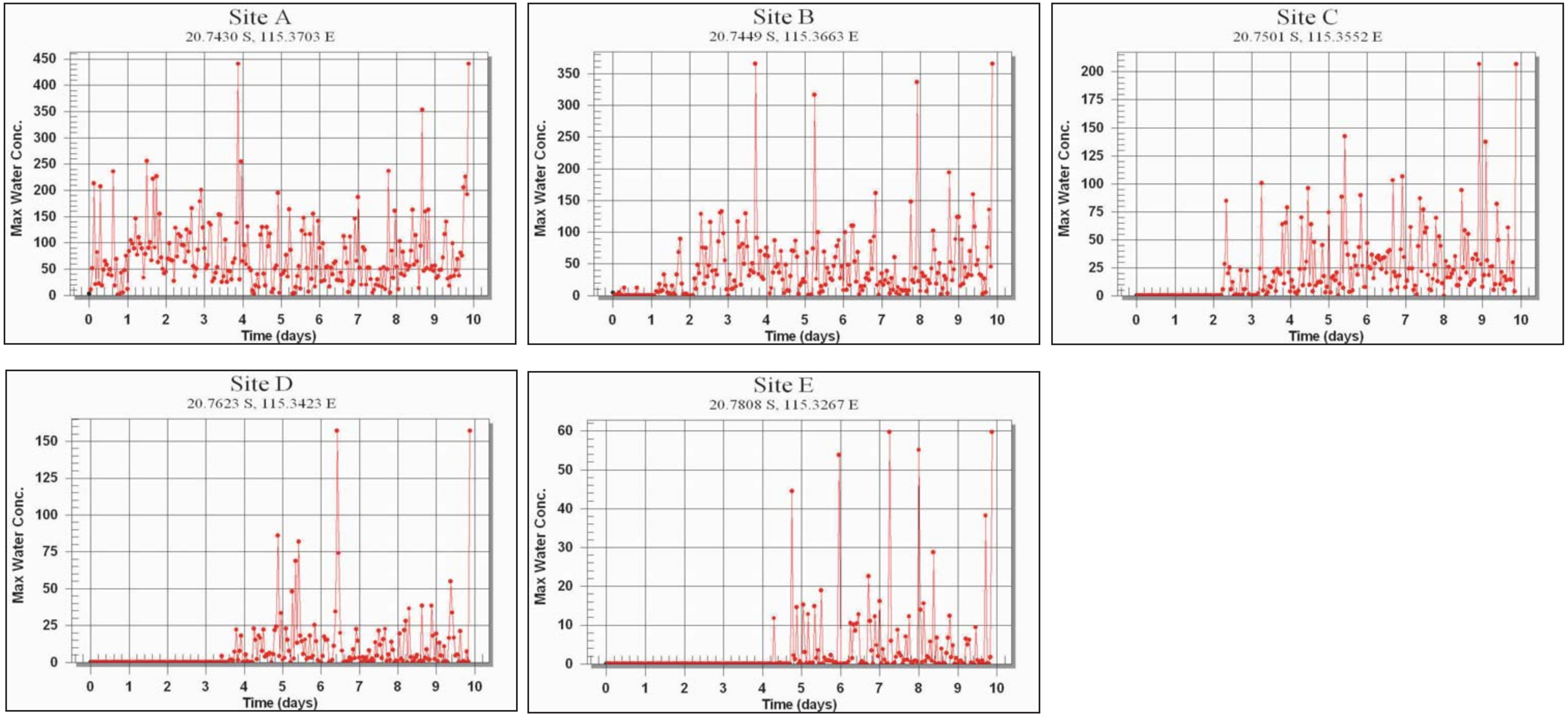

Figure 8: Time-varying concentrations of suspended sediments predicted for locations indicated in Figure. Note (1) the scale of the vertical axis varies among plots to highlight variations at each site (2) the point shown at last time step is the maximum value during the period.

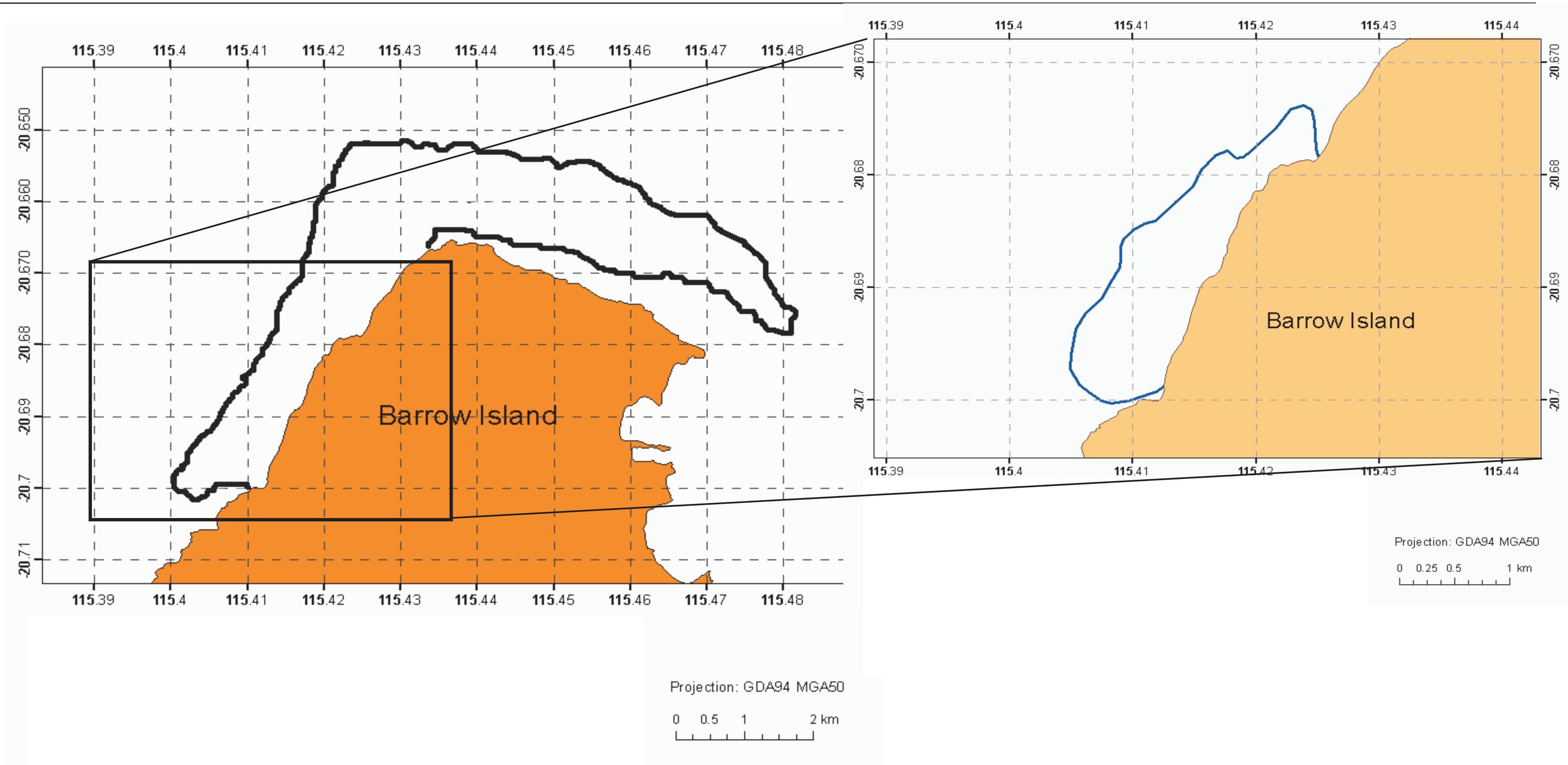

Figure 9: Locations where suspended solid concentrations are expected to exceed 25 mg/l due to bentonite discharge at North White's Beach. The main image shows locations where >25 mg/l are expected for at least 1 hr per day for 5 consecutive days. The inset shows locations where > 25 mg/l are expected for 6+ hours during daylight hours for at least 2 consecutive days.

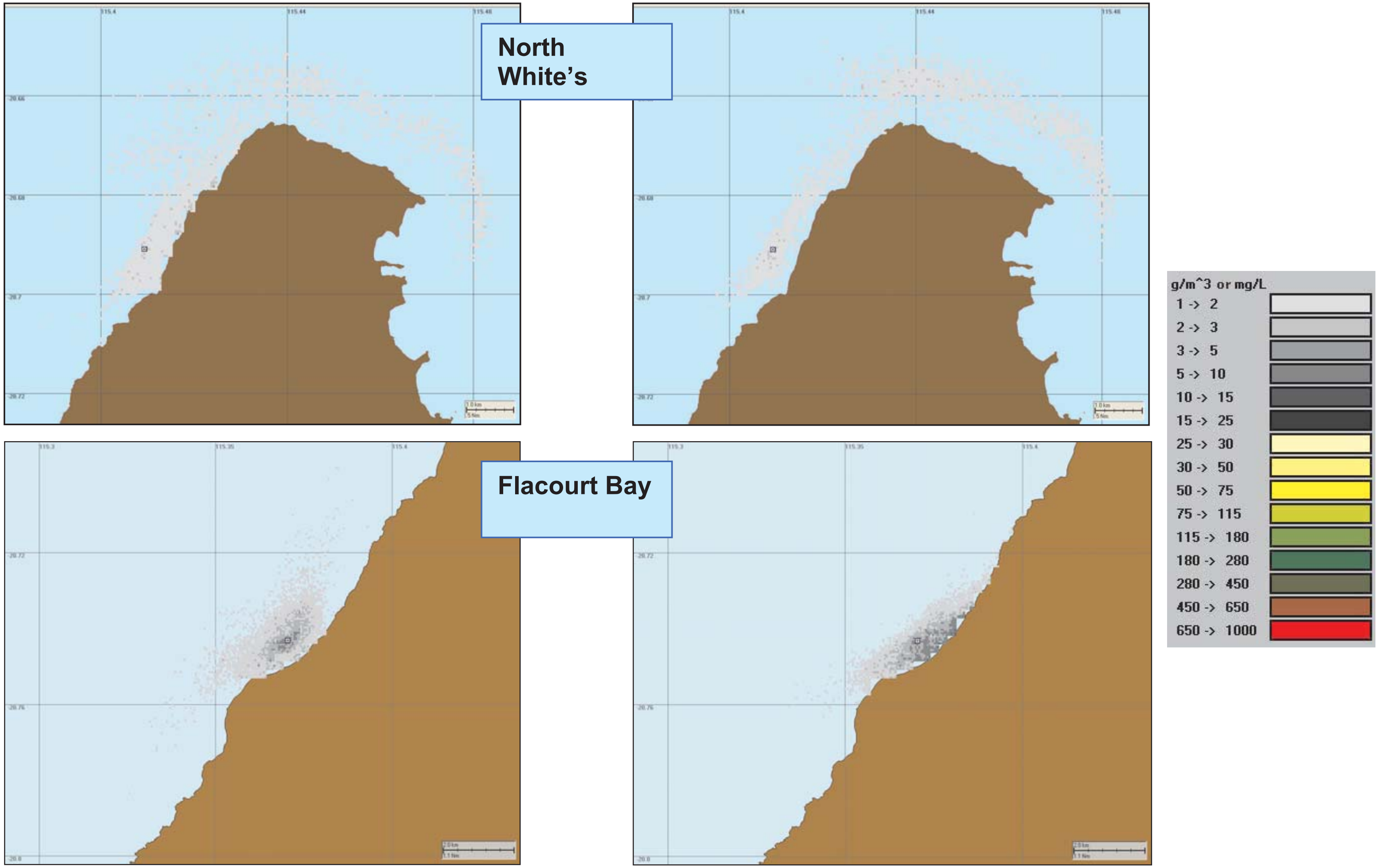

Figure 10: Examples of the maximum instantaneous concentrations of suspended solids predicted from discharges of cuttings with polymer. Each figure shows the outcome from 10 days of discharge given a different 10-day sample of currents. Left figure is from June, right figure is from December. Inset shows the location of the views.

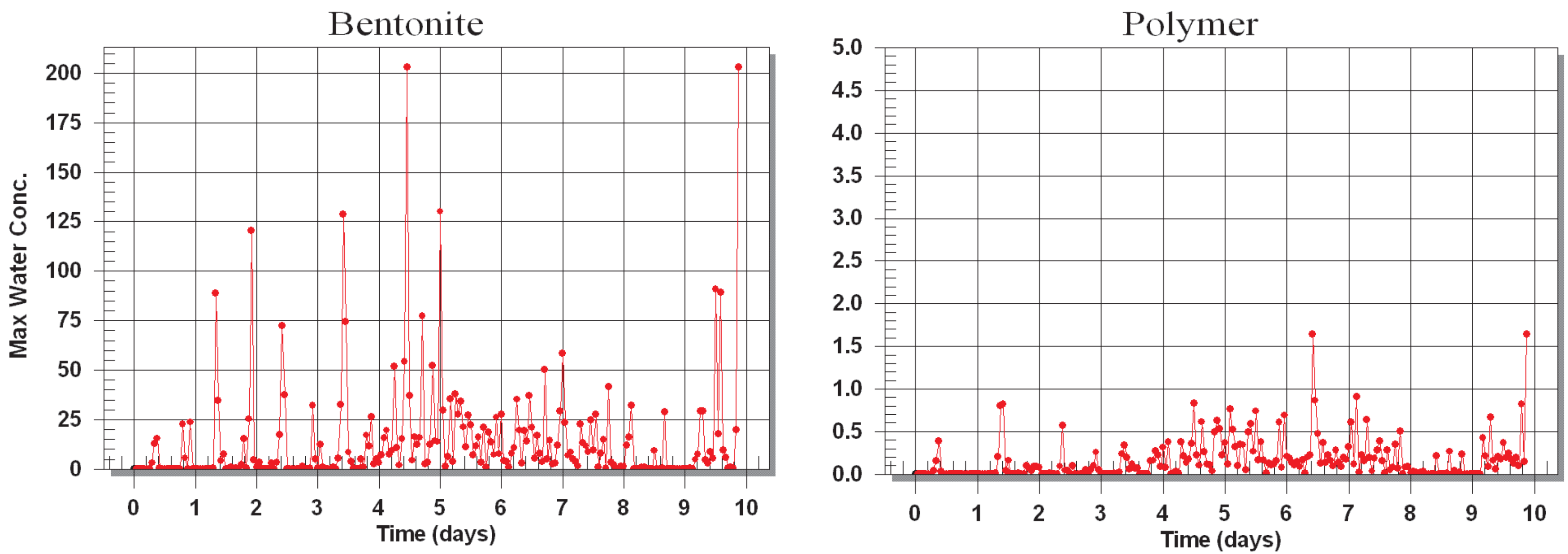

Figure 11: Comparison of the suspended solid concentrations predicted for Biggada Reef for discharge off Flacourt Bay using (a) bentonite clay and (b) water-based polymer. Note that the vertical axes differ between plots.

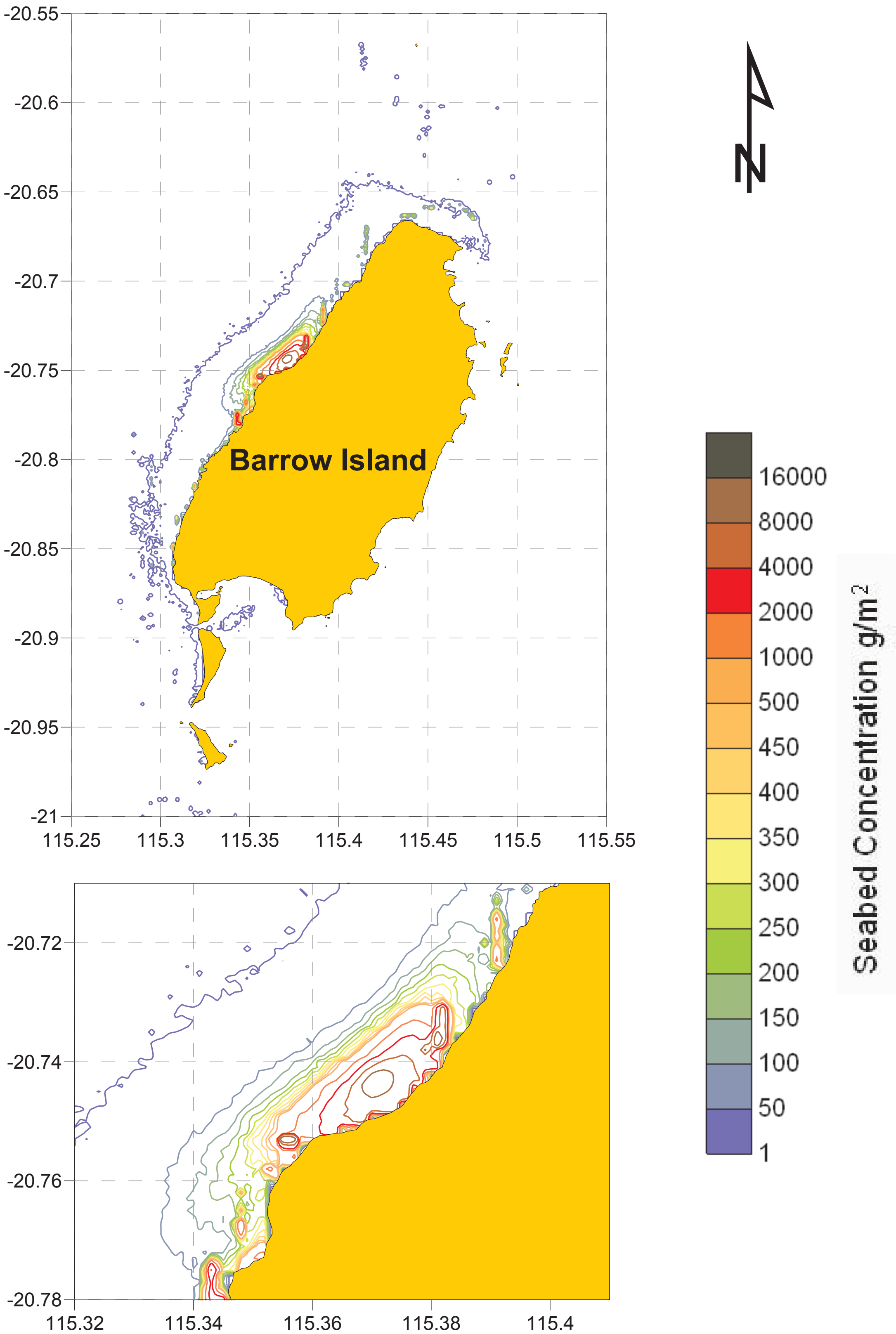

Figure 12: Contour plots showing the cumulative sedimentation predicted for discharge of bentonite and cuttings off Flacourt Bay, assuming no re-distribution of sediments after initial settlement.

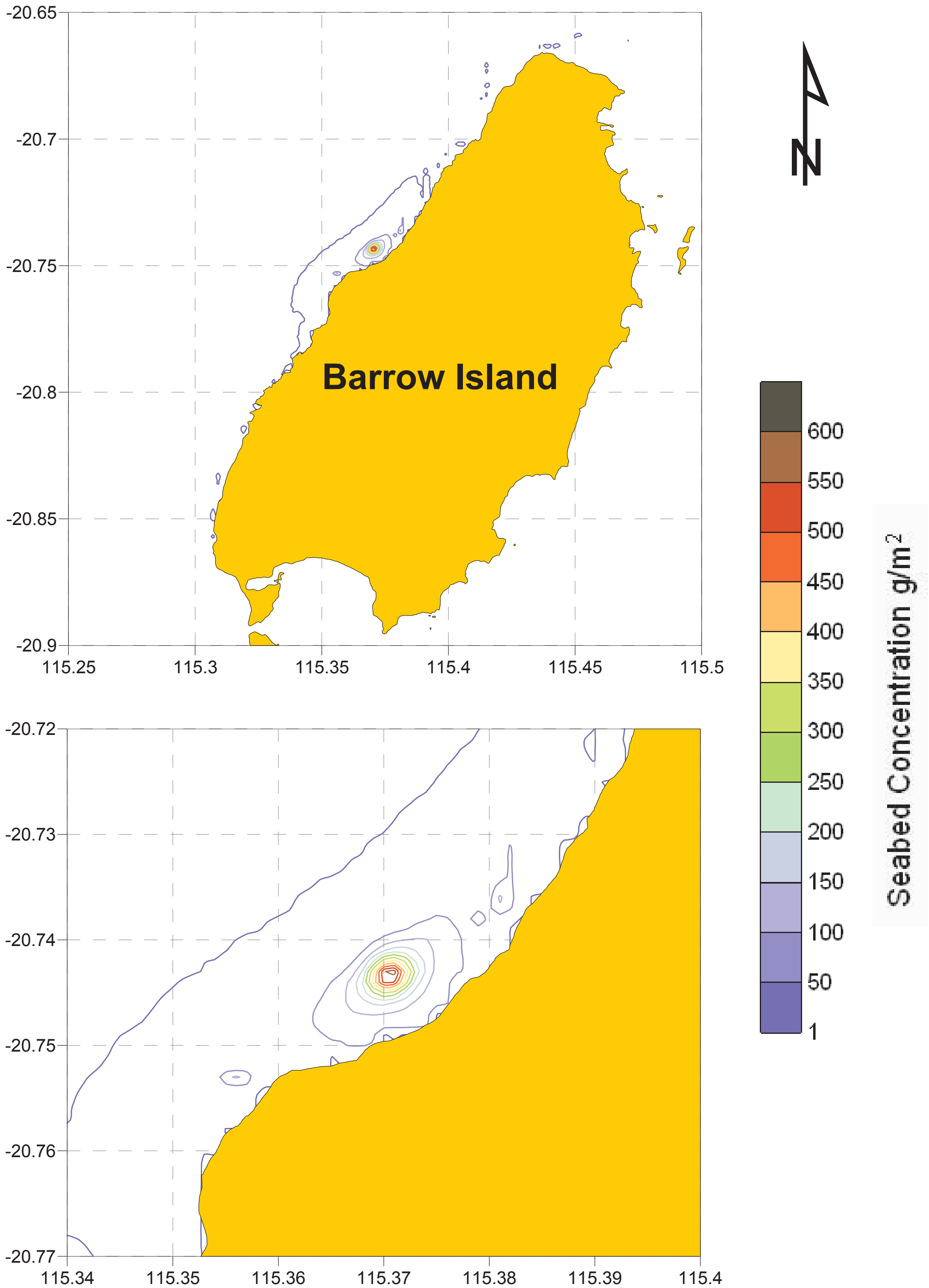

Figure 13: Contour plots showing the cumulative sedimentation predicted for discharge of polymer and cuttings off Flacourt Bay, assuming no re-distribution of sediments after initial settlement.

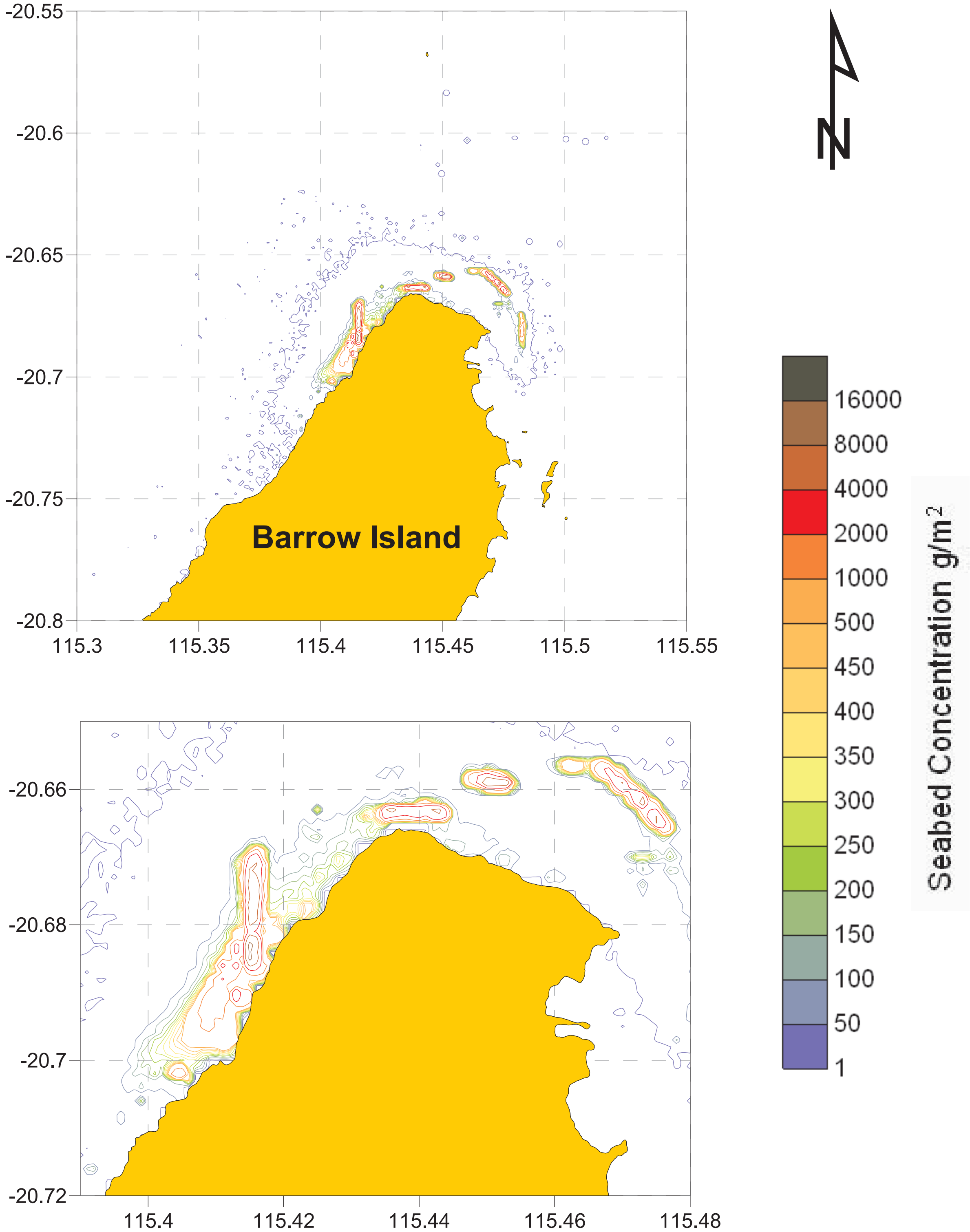

Figure 14: Contour plots showing the cumulative sedimentation predicted for discharge of bentonite and cuttings off North White's Beach, assuming no re-distribution of sediments after initial settlement.

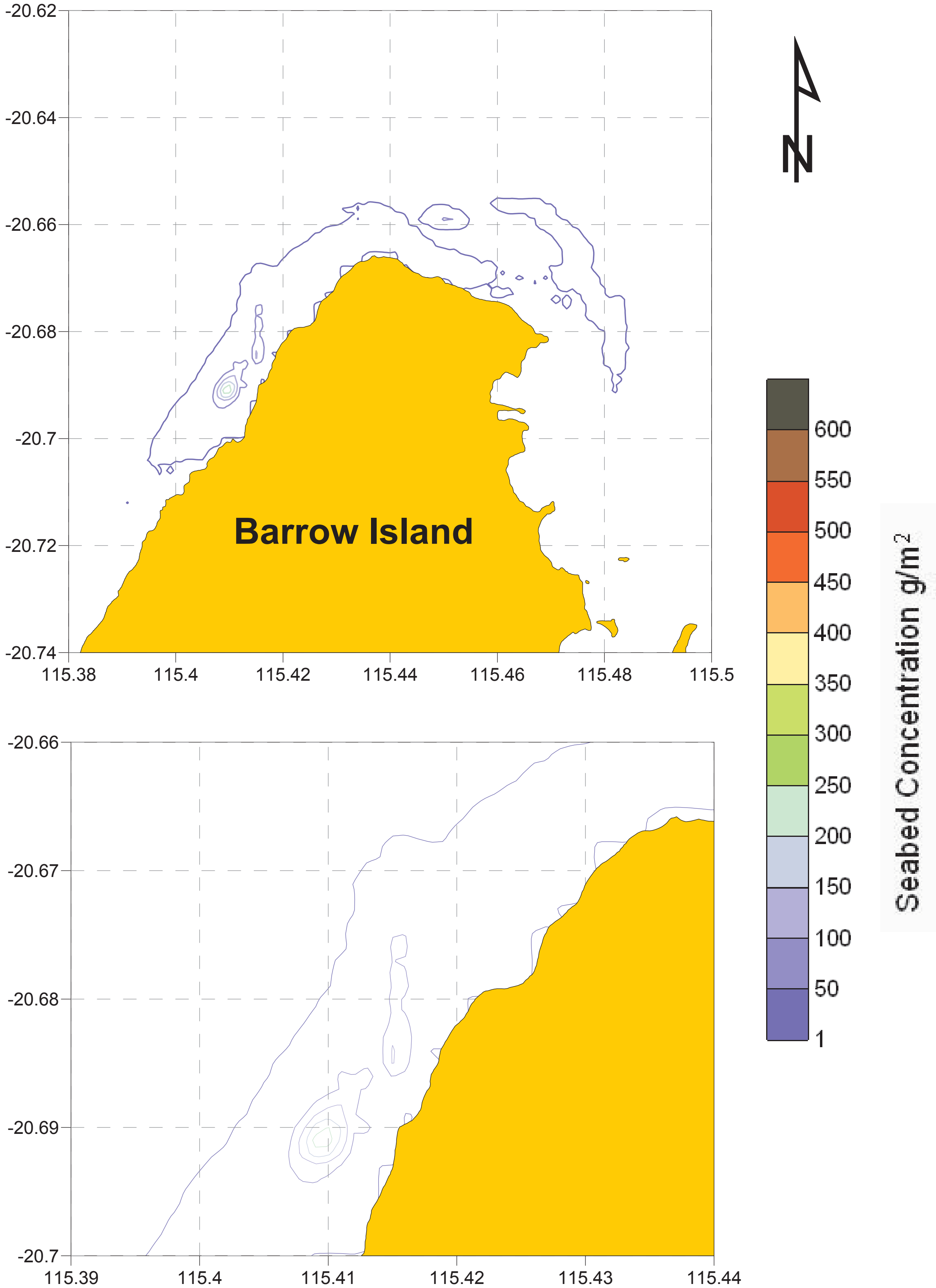

Figure 15: Contour plots showing the cumulative sedimentation predicted for discharge of polymer and cuttings off North White's Beach, assuming no re-distribution of sediments after initial settlement.

5 References

Langtry, S. (2003) Validation of the HYDROMAP/MUDMAP modelling system: Predictions for the fate of sediment discharged to Cockburn Sound. Report to DAL Science & Engineering Pty Ltd and the Defence Corporate Services & Infrastructure. September 2003.

Livingston R.D., R. Shaw, B. A. King, S Zigic and A.V. Valentine (2002) Modeling and field investigations of drill cuttings and muds in the Gulf of Thailand. In Proceedings of the 6th SPE International Conference on Health, Safety & Environment in Oil and Gas Exploration and Production, March 2002.

Teeter, A.M. (1998) Cohesive sediment modelling using multiple grain classes, Part 1: settling and deposition. Proceedings of INTERCOH 98 – Coastal and Estuaries Fine sediment Transport: Processes and Applications, South Korea.

Swanson, J., Isaji, T., Clarke, D. & Dickerson, C. (2004) Simulations of dredging and dredged material disposal operations in Chesapeake Bay, Maryland and Saint Andrew Bay, Florida. Proceedings of the 36th TAMU Dredging Seminar, WEDA XXIV, 6-9 July 2004, Orlando Fl.

Milligan, T.G., D.C. Gordon, D. Belliveau (1996) Fate and Effects of Offshore Hydrocarbon Drilling Waste. Environment Canada web-site (http://www.mar.dfo-mpo.gc.ca/science/review/1996/Milligan/Milligan_e.html)

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