APPENDIX 2: EXERCISE TO EXAMINE OPTIONS AND COSTS FOR THE REHABILITATION OF A DAMAGED REEF AREA FOLLOWING A MAJOR PHYSICAL IMPACT.

Damage estimation

In the exercise described here, a structure (for example a large vessel) has been driven across the reef top inflicting direct physical damage on the coral in the region 60m x 150m. In addition to the physical damage, an area twice as large has been affected by the release of on-board pollutants, so the total area affected is 3 x 60m x 150m.

The effects will differ in two regions: the central region damaged physically by the impact; and the outer region damaged by the release of pollutants. Virtually all larger corals and many small corals will be damaged in the central region. Coral cover would be reduced from approximately 30% to 60% on a thriving reef front and top to less than 5%. However it is likely that many smaller corals would survive in the surface relief provided by dips and crevices in the reef structure.

On a backreef area with scattered patch reefs, or on a reef previously damaged (for example by a severe cyclone or by crown-of-thorns starfish predation), the changes are likely to be less dramatic. There might be a reduction in cover from 10% to 25% to less than 5%. The smaller corals that are most likely to have survived starfish predation or cyclone damage are the same ones most likely to survive a severe physical impact.

The associated effects of the release of on-board pollutants are difficult to predict because of the number of variables affecting the outcome. Corals vary in their ability to protect themselves from adverse conditions, for example by covering themselves with a mucus coating. It is likely that reef top corals in general are better able to protect themselves than deep water corals because of the wide range in normal conditions they encounter. Maximum impact would result from release of a highly toxic pollutant immediately before low tide in the middle of a summers day with current patterns subsequently carrying the pollutant across the reef. The coral mortality resulting from the worst scenario described above would probably be in the range of 30% to 80% of corals. However, if the spill of pollutants occurred in the evening on a rising tide, if currents carried the pollutant off the reef and the product was not particularly volatile, the mortality rate is likely to be closer to zero.

Where corals are killed by the effects of the pollutant the major difference from the central affected zone is that the skeletons of the dead corals remain intact. The significance of this factor in recovery is discussed later.

Definition of recovery

'Normal' reefs can vary widely in the range of hard coral cover encountered, both between zones on the same reef and between similar zones on different reefs. For a reef front and reef top used as an example here, coral cover on a thriving reef is likely to range between 30% and 60%. The figure may be higher for a reef shoulder and lower for the sandy outer reef flat. On backreef areas, the coral cover may fall in a similar range as the forereef for a ring reef with a backreef flat and slope, or for a reef with scattered patch reefs there will be large areas of sand between bommies with generally (but not always) lower cover (approximately 25% to 50%).

For a damaged reef to be rehabilitated so that it appears similar to a 'normal' reef, a cover of approximately 20% to 30% would be necessary. A badly damaged reef would be substantially improved by the establishment of a coral cover of 10% to 15%. Once a cover of this level is achieved, the relatively rapid growth rate of the corals free from competition with neighbours

would result in a near normal coral cover in 1 to 3 years. These two objectives, that is to achieve a coral cover of about 30%, or a cover of about 15%, are used in subsequent examples.

Estimate of likely recovery time without intervention

Before any attempt is made to re-establish the coral population, it must be determined if the physical structure of the reef is damaged, for example, a channel driven over a reef top may alter drainage patterns from the reef top. Under these circumstances, few corals might survive, and nearby undamaged areas could also be affected. The first step in rehabilitation is to assess and repair any physical damage.

The second step must be to remove or neutralise any remaining traces of released pollutants that might reduce coral survival or recruitment. Such a process would depend on the chemical released and is beyond the scope of this report.

The two techniques for re-establishment of the hard corals are:

(i) transplantation of corals from nearby undamaged areas, and
(ii) methods that accelerate coral recruitment.

A problem arises in the affected central section where the reef surface is most likely sheared smooth. Here there is no place to attach the corals and special supports would have to be hammered or drilled into the reef surface. This would require greatly increased manpower over the option of scattering unattached coral pieces.

One of the limited number of circumstances where accelerated recruitment might be considered is when an impact results in large smooth areas of reef, which are not a favoured settlement surface. By adding relief to such a surface, for example by drilling a series of holes or adding grooves in the surface, it is possible that the rate of recruitment might be greatly enhanced, although such a procedure has not yet been tested in practice. This process would be unsuitable for an area of high sedimentation as the holes or grooves would fill with sand and be unsuitable for coral recruits. It would be unnecessary where good surface relief remains.

Costing exercise

In the exercise simulated below for the purpose of calculating costs, we assume a reef is 60 km from the coast, so a large boat is needed. The cost of the boat charter and a team of 4 experienced divers including their equipment, air fills and use of small boats is estimated conservatively to be $2000 per day. We assume that the distance from the damaged area to the suitable site for collection of transplants can be travelled in less than 15 minutes, and weather conditions are good for the duration of the exercise.

We assume that the coral cover on the area of reef was 50% before the accident. The coral cover following the accident is 0% in the central zone and 25% in the outer zone affected by pollutants (a mortality rate of about 50%). Corals transplanted into the shallow outer zone can be attached to the remaining coral skeletons, while those in the central zone would require special support structures for attachment, for example, stakes or plugs drilled into the reef, or the use of underwater cement. It would be a waste of collecting effort to transplant unattached corals into this zone.

About 25% of the area is covered by water greater than 3 m deep at low tide, and hence corals transplanted into this deeper area need not be attached. The remaining 75% is shallow reef shoulder, crest and flat.

From our studies, we have found that in one work hour, divers can collect, load and unload enough *Acropora* and pocilloporid corals to cover 10 m^2 of reef with a cover of 25%. For the sake of this exercise, we will assume the divers are experienced and can collect fast enough to achieve 30% cover over 10 m^2 in 1 work hour. The divers are unlikely to be able to spend more than 4 hours each per day collecting and depositing corals, as this does not include preparation or travelling time between sites. We estimate the extra time required to attach the corals with cable ties in areas where skeletons remain is an extra 20% above the collecting time calculated, and if special supports or cement must be used, effort will be increased by at least 100%.

We estimate that to cover the entire area with corals at 30% cover would take 430 work days. Assuming a crew of 4 divers, the exercise would cost $215 000.

To cover the same area with corals at 15% cover would require approximately 112 work days at a cost of $56 000. These costs are much lower because no rehabilitation is necessary in the outer zone since cover of surviving corals was 25%. Costs for both exercises would be proportionally much higher if mortality of corals in the outer zone was higher.

A further option is to omit transplantation onto the central physically damaged zone which is the most expensive component of the work, and the area most likely to suffer subsequent coral mortality. If the area was instead treated to optimise natural recruitment by adding physical relief to the soothed surface, this might accelerate natural recruitment at relatively low cost. We estimate that the area could be scored with an underwater drill or hammer and chisel in approximately 8 work days. Combined with transplanting corals to the 15% coral level in the deeper central zone, the cost would be $22 500.

With the exception of a coral viewing site near a tourist resort, it is difficult to envisage a situation where a small section of reef, such as that described for the purpose of this exercise, would be important enough to justify an expenditure of between $22 000 and $200 000 to accelerate a process that would occur, naturally in 5 to 10 years. There is no guarantee that a cyclone the week following rehabilitaton would not destroy the vast majority of the transplanted corals. We believe that under such circumstances the physical structure of the damaged section should be examined carefuly to ensure no changes in tidal flows across the reef that might have wider effects. If not, the case for each incidence of damage must be assessed on its merits, and unless there are pressing aesthetic or commercial reasons for the value of that reef area, the benefits of intensive rehabilitation are small. The area should be monitored at intervals of 1 to 2 years to ensure that the recovery process proceeds as expected, whether or not efforts at rehabilitation are made.