INSTITUTE OF APPLIED SCIENCES

THE UNIVERSITY OF THE SOUTH PACIFIC

Environmental Monitoring - Denarau Marina Development

IAS ENVIRONMENTAL STUDIES REPORT NUMBER: 70

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ENVIRONMENTAL MONITORING

DENARAU MARINA DEVELOPMENT

SUMMARY

The Institute of Applied Sciences at the University of the South Pacific has been involved in monitoring environmental impacts of the Denarau Marina Development project since 1991. Baseline studies for this project were carried out in July, September and December of 1991 and again in July of 1992. During these visits, dredging of the marina site and the navigational channel had not started. At this time the coral reefs exhibited good growth, except for a few dead colonies which most probably fell victim to the Crown-Of-Thorns starfish. The seagrass beds adjacent to the site were thriving. This report details the findings of the monitoring visit to the site made in September 1993. During the period between July of 1992 and this visit two catastrophic natural events occurred in Fiji - a major tropical cyclone (Kina) hit the Fiji Islands causing massive destruction and flooding, followed by another severe flood in the Nadi region. As well as these events, dredging of the marina site and channel had started. Because of the coincidence of these events the relative effects of each on the water quality and marine life around Denarau could not be accurately separated. The combined effects however, were severe.

The visit to the Denarau study site by the USP team in September and October of 1993, revealed massive destruction to specific coral assemblages of the genus *Acropora*, at all sites. The more robust and encrusting corals such as *Porites*, *Leptastrea* and *Favia* genera were not effected. In terms of relative amounts of coral death, the offshore sites experienced more harm than the inshore site. **From this observation it is concluded that the greatest impact on the coral reefs at Denarau were probably caused by the tropical cyclone and the floods rather than the dredging operation.**

Problems associated with the dredging operation however have resulted in a total inundation and elimination of the seagrass beds fringing the river mouth along the marina landfill toward the Regent Hotel. **The seagrass beds were found to be completely smothered by silt and their recovery is uncertain.**

The importance of maintaining a healthy and secure marine environment adjacent to a major tourist resort where water sports activities and the marine location bears a significant part of the resort's livelihood should not need to be emphasised. Preparing a long term formal environmental plan for the operation of the marine activities must therefore be considered as a priority.

INTRODUCTION AND BACKGROUND

Denarau Island, a deltaic island within the delta of the Nadi river, has progressively been developed as a tourist resort over the last twenty-five years or so. The expansions to the existing resort, which started in the mid-eighties, are part of the Denarau masterplan which aims to create a fully integrated international resort destination. The focal points of the development are a championship 18-hole golf course, a marina, a Fijian style shopping centre and a cultural centre. The Denarau Island Resort Development Project is the largest single tourism development project in the South Pacific covering some 500 hectares and costing over F$300 million.

The University of the South Pacific (Institute of Marine Resources) carried out two earlier environmental surveys for the Denarau project (Raj and Seeto, 1986; Seeto et al., 1989). The findings from these surveys had been incorporated by HGCL (Harrison and Grierson Consultants Ltd., NZ) and KRTA (NZ) Ltd. into an EIA document for EIE International Corporation.

The present study is part of a third series of studies being carried out by the USP to monitor the effects of dredging a section of the Nadi river estuary to develop a marina and an associated navigational channel. The marina site which is about 9 ha in area would be dredged down to the -3.5 mRL contour, using suction techniques (Anon., 1989). Baseline surveys of the sites were carried out in July, September and December of 1991 (Lovell et al., 1991) and again in July 1992 (Lovell and Odense, 1993).

This report presents results of the monitoring visit carried out on the 29th and 30th of September, 1993 and in October, 1993. By the time of the visit, dredging of the estuary was well under way. The results obtained from these visits however, could not solely be attributed to the dredging operation. More importantly perhaps were the effects of the major cyclone (cyclone Kina) that hit the Fiji group early in 1993 and just as devastating were the floods that hit Nadi town in February of 1993.

METHODS

Environmental assessment methods of the impacts from the dredging operation were basically the same as those established during the initial baseline inspection (Lovell et.al., 1991). As well as the aerial photography and re-photography of the quadrats in the coral reef areas, water quality was assessed chemically at six sites within the area.

a) Water quality assessment

Of the six sites, sites 1, 2 and 3 were identical for the water quality tests and the coral reef quadrats. Sites 4, 5 and 6 were in no way related to the coral reef sites. The location of the six water quality sites are shown on Fig. 1 below.

On-site measurements included water temperature, dissolved oxygen, salinity and clarity. Conditions were very rough making it difficult to take measurements from the boat and so measurements were taken in waist-deep water just off the sand cays in the case of sites 1, 2 and 3. At site 4 located just offshore from where the Nadi river discharges into the sea, no measurement of temperature, salinity or dissolved oxygen could be made from the boat because of very rough conditions. Clarity measurements using the secchi disc was done on the boat with great difficulty.

Water samples were collected from the six sites and analysed in the laboratory at the Institute of Applied Sciences, USP for total dissolved solids (TDS), and total suspended solids (TSS).

Water quality sites location and description

Site 1:

Alacrity cay, site 1 (same as coral reef quadrat site 1), there was much coral rubble on the cay. Measurements and water sample were taken during sunny conditions, outgoing tide, and choppy seas.

Site 2:

Alacrity cay site 2, on the east side of the smaller sand cay. Water was relatively clear but choppy seas. Measurements and water sample taken during mid-morning and outgoing tide. Conditions warm and sunny.

Site 3:

Malan cay, slightly inshore from sites 1 and 2. Conditions were warm and sunny, seas choppy.

Site 4:

Further inland from sites 1, 2 and 3 but just offshore from mouth of north Nadi river. Site 4 is nearer the plume. No measurements of salinity, temperature and dissolved oxygen could be made from the boat because the sea was very choppy. Only clarity could be measured.

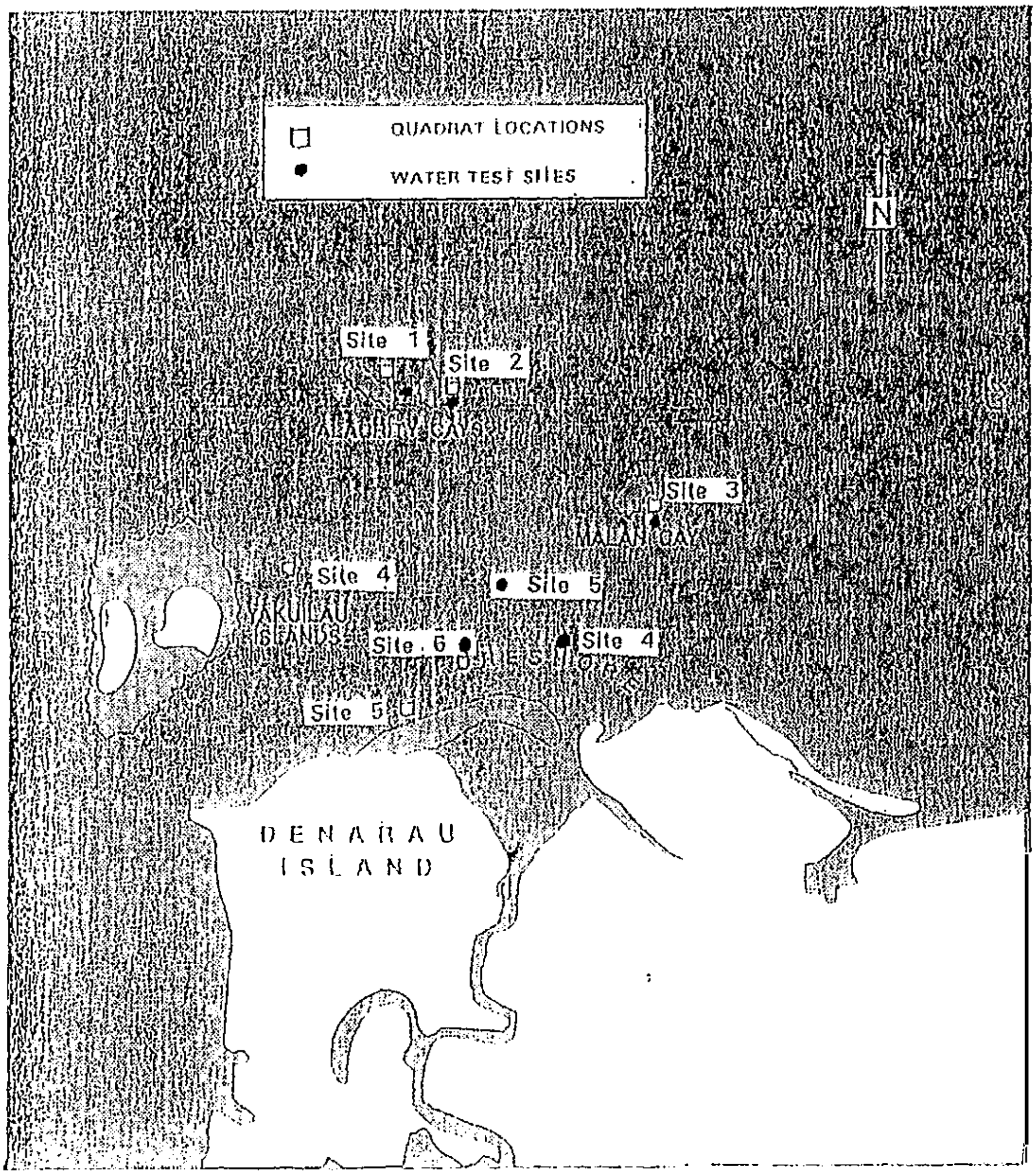
Site 5:

Measurements and water samples for sites 5 and 6 were taken on Thursday morning 30 September, 1993 during warm, sunny but windy conditions. The sea was quite choppy. Site 5 was located just beyond the plume from the dredging operation and offshore from the dyke.

Site 6:

Measurements were taken soon after site 5 was assessed. Site 6 was located further inshore from site 5(site nearest to the development) and within the plume.

Figure 1: Location of Quadrat and Water Quality Test Sites.



b) **Coral reef assessment**

With regards to the coral reef sites, the site numbers reflect the establishment of the sites and not their distance from the development. Site 5 is adjacent to the mouth of the north Nadi river. Sites 3, 2, 1 and 4 represent the sequence of locations with increasing distance from shore. These sites are described qualitatively and by periodically re-photographing of discreet photopoints. The photopoints consisted of one metre square quadrats, defined by permanent markers and utilising a frame and guide for consistent re-photography.

c) **Aerial Survey**

The aerial photography was carried out at midday on September 30, 1993 during low tide, as was done previously on July 10, 1992. The flight altitude was 500m and 28mm and 50mm lenses were used.

RESULTS

a) **Water quality**

Temperature, salinity, dissolved oxygen (DO)

The temperature did not vary significantly between the six sites. What variation that existed was related more to time of sampling (early or mid-morning) than to other factors.

The salinity varied from 30 parts per thousand (ppt) to 32 ppt. The off-shore sites, sites 1, 2 and 3 had higher salinities, having less influence from Nadi river discharge.

Values of dissolved oxygen varying from 6.2 to 7.4 parts per million (ppm) indicated oxygen saturation for all six sites.

Clarity

Clarity values indicated a clear trend as one moves further away from the dredging site. Clarity was lowest at site 6, within the plume from the dredging operation, and increasing further off-shore. Sites 1 and 2 had highest clarity.

Total dissolved solids (TDS)/Total suspended solids (TSS)

Values of TDS did not vary much for the six sites. However there was some large differences for values of TSS. Generally speaking, inshore sites (sites 5 and 6) had higher values of TSS and this is to be expected since the dredging operation in the area was producing a very extensive plume.

TABLE 1 : Water Quality Data for Selected Sites off Denarau Island
: Date 30/9/93

Sample	Lab No.	Tot Susp. Solids mg/l	Tot Diss. Solids g/l	Temp. °C	Salinity ppt	Diss. O_2 ppm	Clarity (m)
Site 1	93/1991	29.6	39.7	24	32	6.4	5
Site 2	93/1992	5.2	37.7	24	32	6.6	5
Site 3	93/1993	6.0	39.3	26	32	7.4	3.5
Site 4	93/1994	10.0	38.8	N/A	N/A	N/A	2.5
Site 5	93/1995	54.8	38.8	25	30	6.4	3.7
Site 6	93/1996	28.8	39.9	24	30	6.2	1.7

b) Coral reefs and seagrass beds

Site 3:

This is the inshore site located on Malan Cay. It chronically experiences turbid conditions. The effects of periodic flooding are more pronounced here due to its proximity to the river. The assemblage has been conditioned by these nearshore effects. Due to this tolerance, changes in the monitoring quadrats are minor when compared with the offshore sites.

Quadrat 1: Mortality is limited to two colonies of *Acropora selago*. The other colonies are exhibiting growth. These species are massive forms, characteristic of inshore conditions *(Favia pallida, Leptastrea pallida and Psammocora contigua).*

Photo 1: Malan Cay: Site 3; Quadrat 1
January, 1991

Photo 2: October, 1993

Quadrat 2: Good growth in the species *Acropora selago* was observed between the two baseline survey periods. All of the colonies (6) died in the intervening period to this inspection. Two of the colonies were *in situ* with the other missing. No other mortality was seen with good growth observed in colonies of *Leptastrea purpurea and Porites sp.*.

Photo 3: Malan Cay: Site 3; Quadrat 2
July, 1992

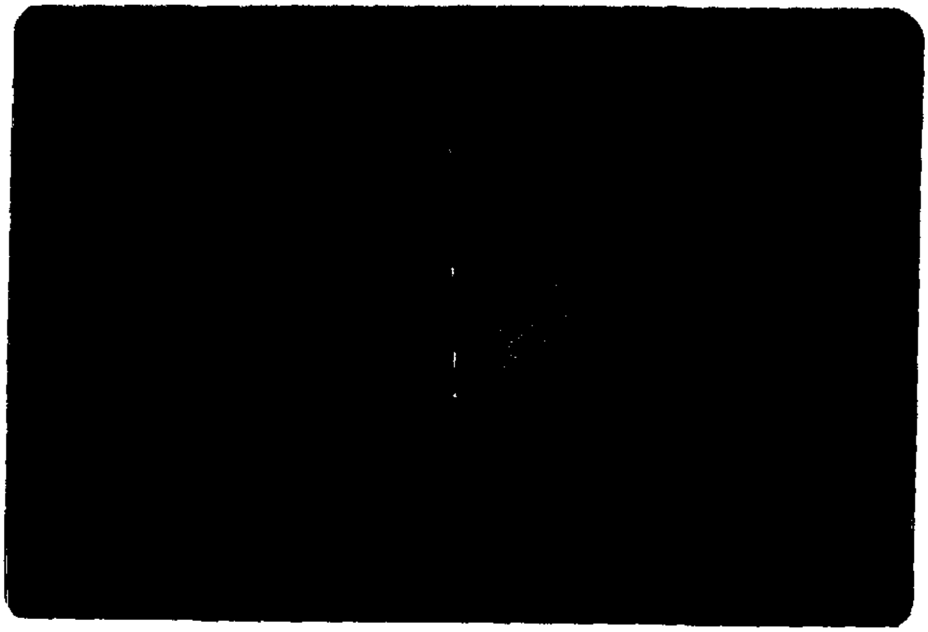


Photo 4: October, 1993

Quadrat 3: Mortality occurred in the *Acropora selago* recruits, observed in the second visit. The rest of the colonies appeared healthy.

Photo 5: Malan Cay: Site; quadrat 3
July, 1992

Photo 6: October, 1993

Site 2 is located on the northern most Alacrity cay. The distance offshore provides a buffer for the nearshore influences which allow this area to develop an *Acropora* dominated community. As the result of the cyclone or the February flood massive coral death has occurred. This area is characterised by 100% mortality of the corymbose *Acropora*. The buffering of depth has allowed a few members of this genus to survive. This area is unique in that it is frequented by tourist divers and as such anchor damage is a chronic feature of the area directly behind the cay.

Quadrat 1: A luxuriance of corymbose and tabulate coral cover has experienced total mortality. Most of the colony skeletons are *in situ* but seven colonies have been removed from the quadrat. Removal is also evident from areas around the quadrat.

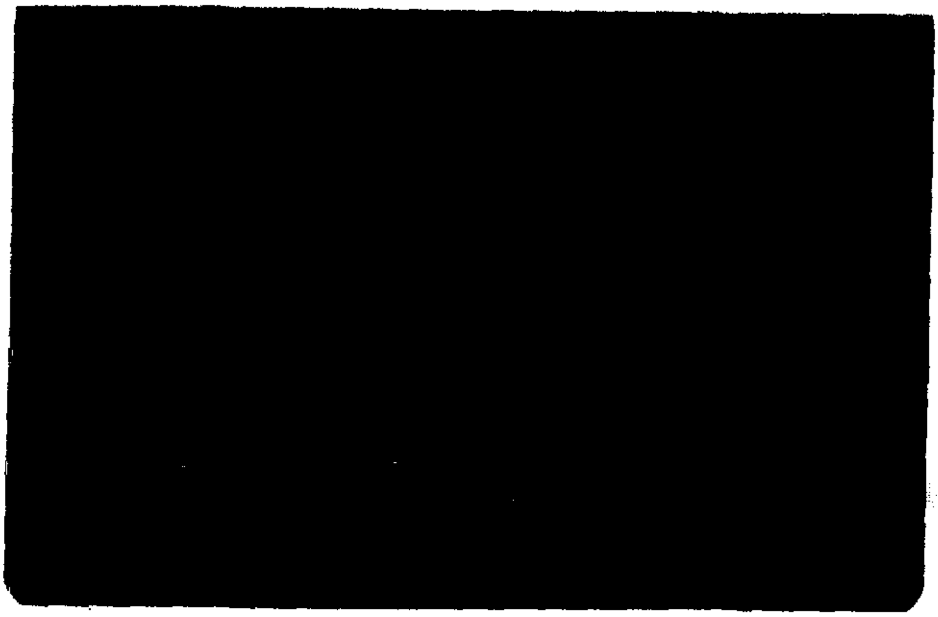
Photo 7: Alacrity Cay: Site 2; Quadrat 1
July, 1992

Photo 8: October, 1993

Quadrat 2: This quadrat has undergone similar change with only two colonies left in position while nine have been removed. Observing the anchoring practices of a tourist boat, it was thought that removal was the result of anchor damage.

Photo 9: Alacrity Cay: Site 2; Quadrat 2
July, 1992

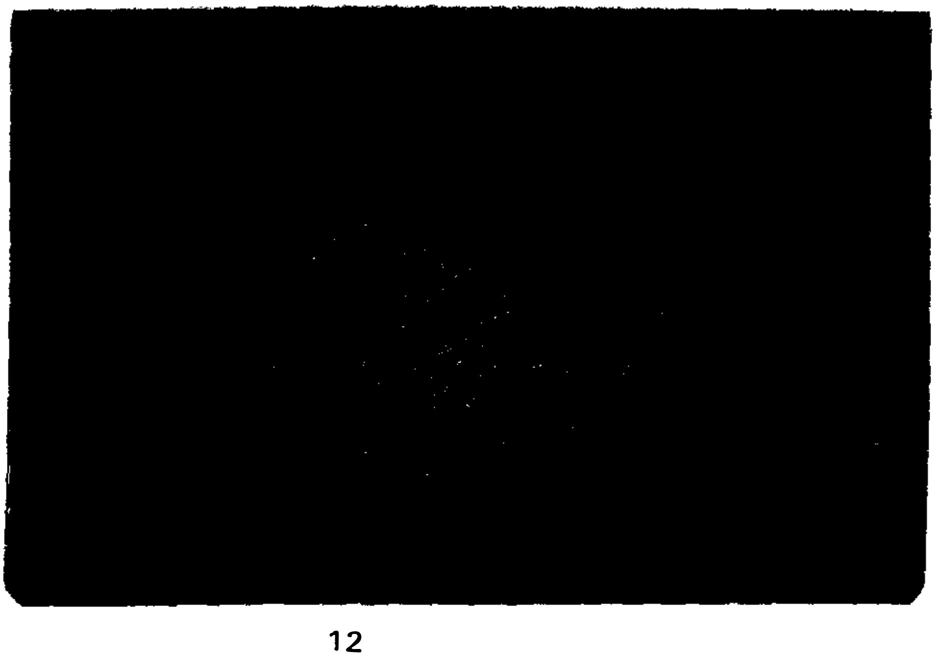
Photo 10: October, 1993



Quadrat 3: Where previously good growth was observed during the baseline observations. Total mortality was experienced in this quadrat. As with the other quadrats, some colonies remain *in situ* while others have been removed.

Photo 11. Alacrity Cay: Site 2; Quadrat 3
July, 1992

Photo 12: October, 1993



Site 1 is located on the west Alacrity Cay. The changes here involve a high proportion of colony removal. Like the reduced coral assemblage, the algal covered substrate has also been reduced.

Quadrat 1: Experienced 100% mortality with respect to the *Acropora*. Three other genera survived the flood and are in apparent good condition. They are the genera of *Favia, Leptastrea, Porites and Psammocora*. As this quadrat is shallow, on the top of a bommie, all of the branching or corymbose colonies were removed.

Photo 13: Alacrity Cay: Site 1; Quadrat 1
December, 1991

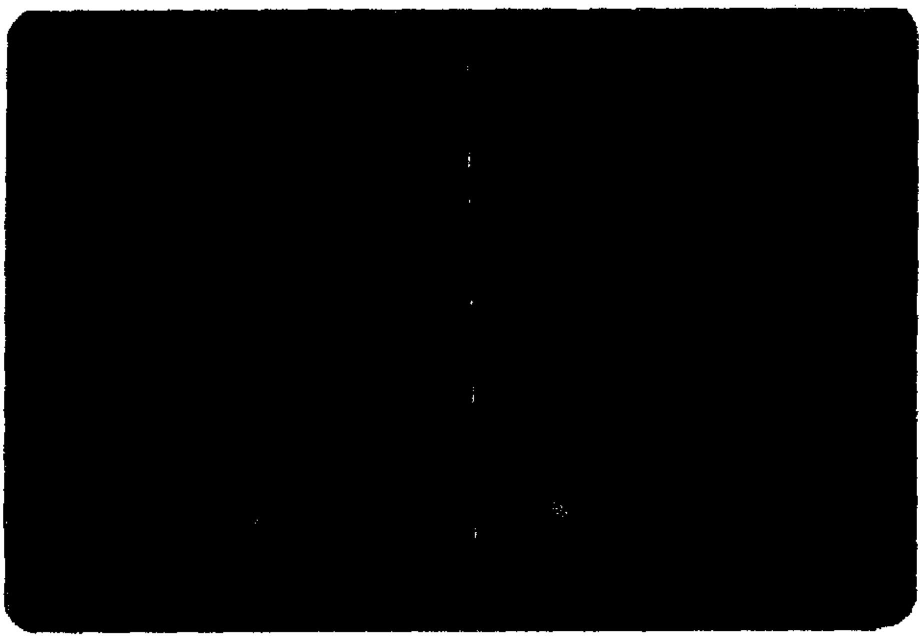
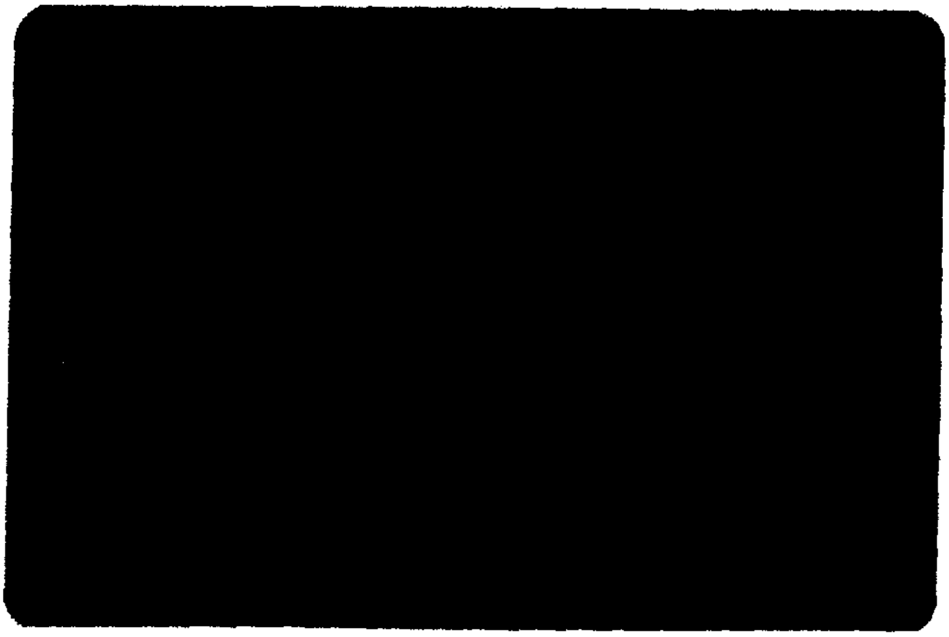


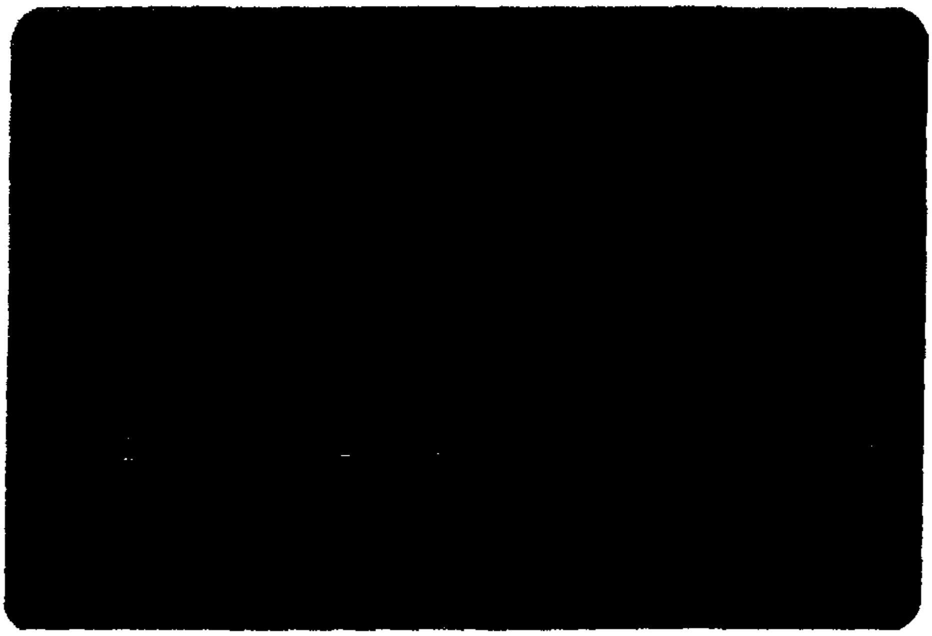
Photo 14: October, 1993



Quadrat 2: The situation here is similar to the situation in quadrat 1. The corymbose *Acropora* colonies have been removed as have two colonies of the *Favidae (Goniastrea favulus).* The massive colonies of four other genera have survived and are in apparent good health. The growth forms of these are characterised by a more encrusting growth form.

Photo 15: Alacrity Cay: Site 1; Quadrat 2
December, 1991

Photo 16: October, 1993



Quadrat 3: All the *Acropora* colonies were removed as well as one each of *Pocillopora damicornis and Porites sp.*. More massive specimens of *Porites sp.* remain. The semi-barren area is covered by a thick brown silt which is more evident in this photo.

Photo 17: Alacrity Cay: Site 1; Quadrat 3
July, 1992

Photo 18: October, 1993

Site 4: Site 4 is located to the north east of Yakuilau Island on a small off-shore patch of reef. It rises from 10m of water. The site is located on the top of this reef patch.

Quadrat 1: Total mortality of the *Acropora* assemblage occurred with the removal of ⅓ of the colonies. The *Pocillopora damicornis* also died. Though of the same family as the *Acropora*, the encrusting sheets of *Montipora* remain unaffected.

Photo 19: Yakuilau Island: Site 4; Quadrat 1
January, 1992

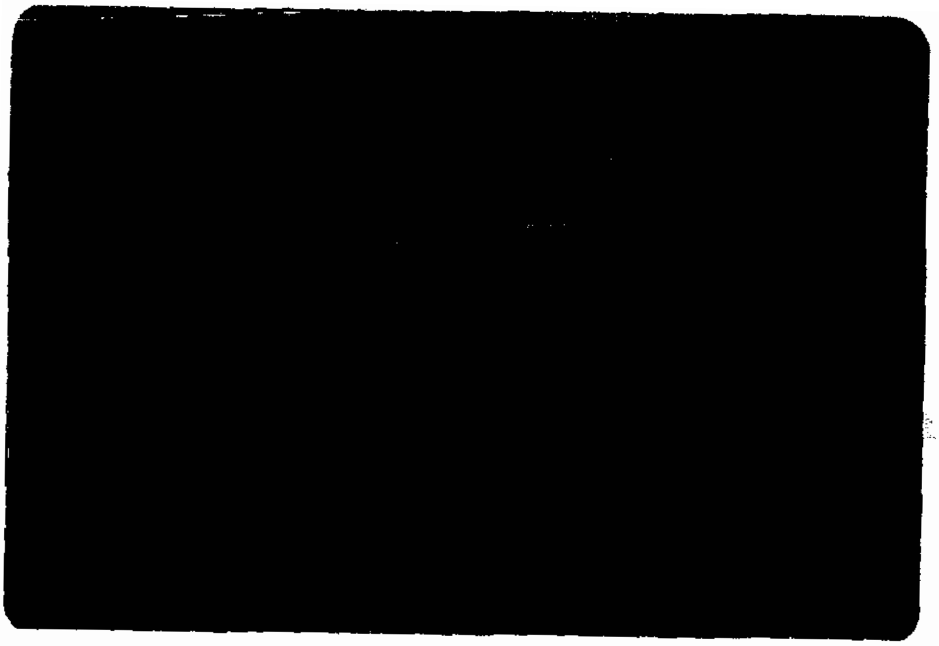
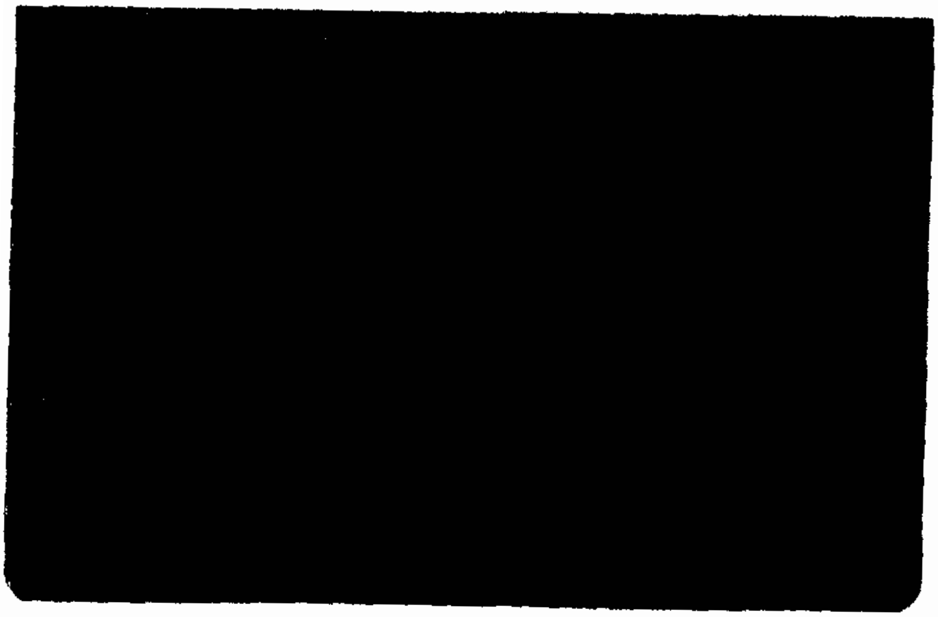


Photo 20: October, 1993



Quadrat 2: This area has been highly perturbed by the evident grounding of a vessel, resulting in the crushing of this study site. Again we see the *Acropora* dead but the *Porites* alive with good growth seen since the last survey.

Photo 21: Yakuilau Island: Site 4; Quadrat 2
January, 1992

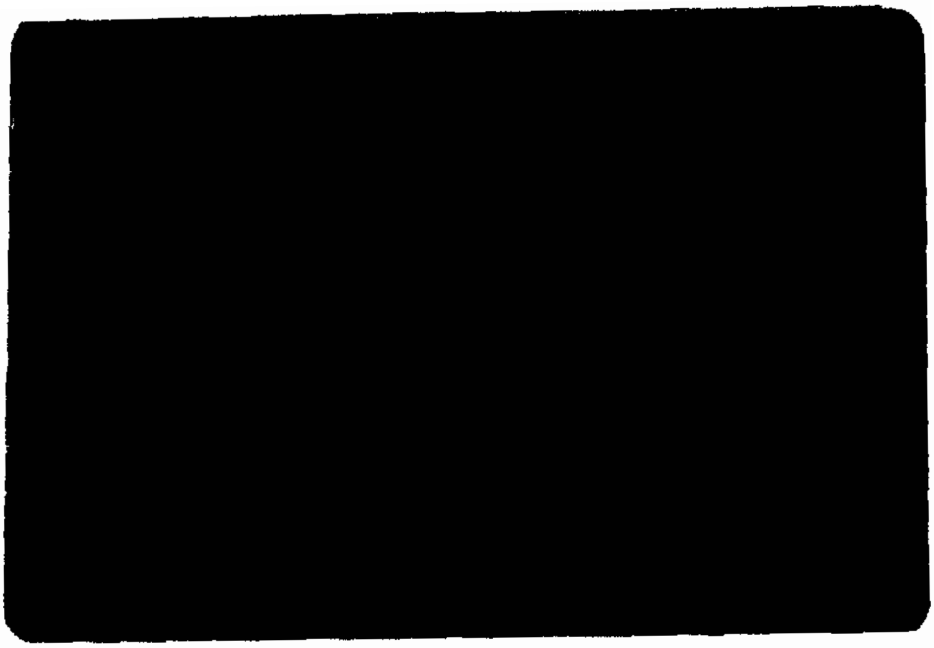


Photo 22: October, 1993

Quadrat 3: The situation is much the same in this quadrat with *Acropora* death and the survival of the *Montipora.* An exception occurs with the survival of two colonies of *Acropora millepora.* This species is more tolerant as the other species *(Acropora hyacinthus, nobilis and secale)* experienced total mortality.

Photo 23: Yakuilau Island: Site 4; Quadrat 3
January, 1992

Photo 24: October, 1993

Site 5:

This site is adjacent to the marina development. Spoil from the operation has been used for land fill along the spit (see photo 27 below). The water borne component is deposited along the foreshore, inter- and sub-tidally. The seagrass beds have been inundated by a fine mud layer which overlays them to thickness of 20 cm. Areas inshore where the spoil has breached the dyke, mud layers are much deeper (> 60 cm). The visibility within the plume is < 1m.

c) Aerial survey

From the aerial observation, the plume from the river mouth extends westward along the foreshore. It was confined to a width of < 200m. No comparison of the seagrass beds could be made from the aerial photographs due to the opaque nature of the plume. The effect to the east is minimal or intermittent as the seagrass remains unaffected as do the inshore coral patches.

Photo 25:

Clear waters and areas of seagrass (bottom left of picture) are clearly evident in areas to the east of the dredge site, seen in part on the top right of the picture. The plume from the dredge site has not affected the eastern foreshore.

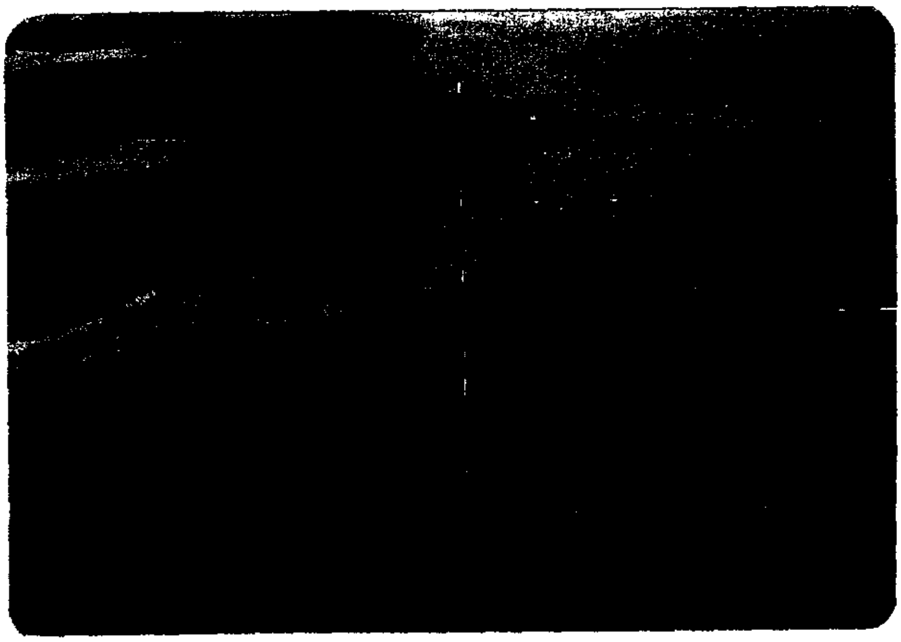


Photo 26:

The success of the dykes in containing the plume is evident in this photograph (lower half of the photograph), and the consulting engineers responsible for this aspect of the development should be commended.

Photo 27:

In an earlier baseline report (Raj and Seeto, 1986), a potential problem highlighted by the authors was the possibility of dumped spoil breaching the dykes. This photograph shows where this problem has occurred in two places and the resulting thick layers of mud and spoil spreading out and smothering the seagrass beds in the area.

SUMMARY

Changes in the nature of the coral composition in the quadrat study sites between monitoring periods.		
Study Sites	July 1992	October 1993
Site 1: Alacrity Cay West	Good coral growth with the *Acropora* dominating. Three other genera present.	100% mortality experienced with respect to the *Acropora*. The genera, often dominant in the inshore (*Favia, Leptastrea, Porites and Psammocora)* survived.
Site 2: Alacrity Cay Northernmost	Luxuriant development of corymbose and tabulate *Acropora* species.	Total mortality of the coral fauna. Seven colonies have been removed.
Site 3: Malan Cay	Coral development poor as compared to the offshore sites 1,2,4.	Relatively unaffected by the cyclone and flood. Coral death confined to the genus *Acropora sp.* as in the offshore areas.
Site 4: Yakuilau Island, patch reef to the northeast	A mixed assemblage dominated by the *Acropora* with large areas colonised by the encrusting *Montipora*.	Total mortality of the genus *Acropora* as well as the species *Pocillopora damicornis*. Good growth seen in the genus *Porites*.

Considering the reef sites as a whole, coral mortality decreased with water depth. The surface waters provided a buffer for the deeper coral fauna. High coral mortality was confined to depths of less than 3m.

The seagrass beds along the foreshore were totally smothered with silt up to a depth of 0.5m. Turbidity of the water in the vicinity of the dredging work was significantly higher than during the 1992 visit. The off-shore coral reefs had suffered substantial mortality. The factors causing these changes are discussed below.

DISCUSSION

The changes found to the marine environment during the September and October monitoring visit were considerable and were related to both natural events and to the dredging of the marina.

Two major events occurred during the period between the monitoring session of July, 1992 and October, 1993. These were cyclone Kina, on January 2-3 and the Nadi flood of February 22-28, 1993. Both of these events were unusually severe.

The effect of Cyclone Kina began on December 30 when 26 mm of rain fell at Nadi airport. On January 3rd, 143 mm of rain fell in Nadi and the rain gauges over-flowed in Lautoka (> 212 mm) with the same on January 4th. Monasavu recorded 550 mm. There was substantial flooding. As the cyclone approached, the wind backed to the east and, then from the south at 50 kts with gusts of 80 kts at 11:53 UTC on January 2nd. The barometric pressure fell to 968.8 mb. From that time, the storm began to moderate with the wind backing to the southwest. During the periods of gale and storm force winds, the direction of the wind was offshore. This resulted in a reduced fetch, minimising the wave action.

During the February flood, Nadi airport recorded 700-800 mm of rain in five days. This was the worst flood since 1985. Prior to that, the largest rainfall was 900 mm in the flood of 1964.

Impacts of tropical cyclones on coral reefs

The most prominent short-term natural agent to cause catastrophic coral mortality on reefs are tropical storms. The mechanical effects of extreme wave action as well as the reduction in salinity, increased turbidity, the alteration in the reef morphology and current structure give rise to alteration of the reef communities and, at times, wholesale death. These community changes involve the reduction of monopolising species, the dispersal of coral fragments which develop into new colonies, new substrate becoming available for settlement. As part of the system within which coral reefs has evolved, cyclones have many beneficial effects on the reefs growth and development.

Impacts of flooding and associated siltation on coral reefs

Understanding the mechanisms by which sediment affects coral is helpful. Firstly, most corals are attached to reef material and cannot move to improve their circumstance. Attachment itself relies on a suitable substrate. Silt covered surfaces are not suitable and the larval stage cannot settle. Feeding is interfered with and the continuous need for cleaning becomes an energy consumptive requirement that depletes the energy budget. Cloudy water prevents the penetration of light, depriving the coral's symbiotic algae, the zooxanthellae, of their energy source. Their contribution to the corals nutritional requirement and skeletal construction are reduced. The skeletal design of the colony is often unsuited to the increase in siltation with its growth form allowing silt capture and smothering (Holthus, 1991).

The concern with respect to this project is that of persistent siltation. With the flood and dredging both contributing to the increase in the amount of silt in the Bay, it is of concern that the chronic turbidity observed may be long lived.

It is well established that siltation directly effects species diversity and the degree of living cover. Bull (1982) in comparing two bays on Magnetic Island, North Queensland, found a marked reduction in species complement with the near absence of *Acropora* in the site most affected by siltation. Roy and Smith (1971) found a 50% lower coverage in turbid areas of the Fanning Island Lagoon. Porter (1972a,b) attributed diversity reduction in back shelf regions of Caribbean reefs to sedimentation. Loya (1972) concluded that heavy sedimentation may be a very significant factor in determining scleractian community structure. He attributed a reduction in species abundance and percentage cover in areas on Eilat Reefs to sedimentation. He pointed out that the few massive species found in this zone have probably evolved cleaning mechanisms. Marshall and Orr (1931), in studying the effects of sedimentation at Low Isles, Queensland found the predominant bay genus of *Favia* to be a very efficient sediment remover.

Deposited sediment may limit the establishment of sessile organisms such as coral. Motoda (1940) explained the paucity of reef corals in certain areas in Palau are due to unfavourable substrates. Kissling (1965) found substrate to be the prime factor in regulating coral distribution in the shallow water environment at Spanish Harbour.

Lovell (1989), in comparing the underlying subfossil reef corals with the present assemblage at Moreton Bay, Queensland, found a marked change had occurred in the composition. The hypothesis for this change included, as a major contributing factor, the chronic presence of suspended sediment and silty substrates.

Coral reefs at Denarau

The coral reefs of Nadi Bay, close to a freshwater river (Nadi River) thrive in what is basically a marginal environment. The ameliorating features are the frequent wind swell, and the fact that the reef areas are raised above the lagoon floor. These features provide a physical setting which helps keep the reef flats clean, allowing reef development as luxuriant as that characteristic further offshore. The soft silt, of terrestrial origin is confined to their inclined margins and the lagoon floor. Only isolated clumps of coral are found there, predominated by species adapted to silty environments i.e. Fungidae.

The effect of cyclones on coral reefs depends on the intensity, direction and the nature of the reef community. The Denarau coast is generally protected from the prevailing winds and is subject to greater damage as the coral growth is less robust. This is particularly so for sites 1 and 2. An exception is site 4, near Yakuilau island where reef development has occurred in an unprotected, shallow area. The robustness of skeletal development in this exposed environment prevented removal by wave action.

Species uncommon on the inshore reefs are seen to settle and thrive in their post-settlement period of approximately 6 months. As species tolerances vary greatly to both high and chronic silt loads as well as their tolerance to freshwater, it is not possible to determine the precise factors which are limiting. The culling effects of these uncharacteristic species may be during periods of floods where a combination of high silt loads and low salinity are extreme. What is clear is that the inshore reef area varies from the offshore in terms of abundance and luxuriance of coral development. If there is a substantial increase in chronic siltation in the offshore areas, then the reef areas will accommodate by adopting an inshore composition (Marszalek, 1981; Roy and Smith, 1971).

As already discussed above, flooding and increased sedimentation often associated with cyclones do have more drastic effects, both directly and indirectly on coral reefs. At Denarau, the study sites, with respect to their increasing distance from the Nadi River, provide us with a natural example of the effects of river discharge on coral reefs. Persistent siltation and periodic pulses of freshwater near the river mouth condition the assemblage differentially thus in general, the inshore site (site 3) has lower species diversity, lower percentage of living cover and a greater predominance of algae. At the offshore sites such as Alacrity Cay and Yakuilau Island, the coral diversity is higher with an abundance and luxuriance of coral growth.

However, the flood damage caused by cyclone Kina, and the flood in February were most likely responsible for the wholesale death of *Acropora* noted at all sites. Only the more robust and encrusting corals survived. However, in his investigation of the coral reefs of Moreton Bay Lovell showed that a reef subject to periodic catastrophic flooding can survive (Lovell, 1989). If the environment returns to its pre-flood state, species number and, to a lesser extent, diversity, is maintained when re-colonised.

In terms of relative amounts of coral death, the offshore sites experienced more harm than the inshore site. From this observation therefore, one can conclude that the greatest impact on the coral reefs at Denarau were probably caused by the tropical cyclone and the floods rather than the dredging operation.

Seagrass beds at Denarau

Seagrass beds are a fundamental component of the inshore marine ecosystem; they represent an important site of primary and secondary production. They are a foundation component of the trophic pyramid. They are both habitat and food source for many benthic herbivores and larger animals like turtles. Fish feed on the epifauna on seagrass blades. Importantly, seagrass consolidate the foreshore area, preventing erosion and the migration of sand.

Problems associated with the dredging operation have resulted in a total inundation and elimination of the seagrass beds fringing the river mouth along the marina landfill toward the Regent Hotel. This problem is a result of deposition from the silt plume together with muds which have breached the dykes where the dredged fill was deposited (see aerial photo 27). Fine silt varying in depth to approximately 0.5m is now found along the foreshore of the dyke where the seagrass once occurred. Raj and Seeto (1986) cautioned against this possibility, pointing out that their destruction would lead to a loss in the primary and secondary production of marine life with significant loss in fisheries productivity.

Interestingly, in one of the earlier EIA documents prepared by HGCL for EIE International Corporation (Anon.,1989), it was predicted that the dyke and navigational channel would not impact adversely upon the seagrass beds. However, that prediction was obviously wrong and therefore some mitigative action is required urgently.

The effects of large amounts of mud deposited on the seagrass beds is uncertain. It is speculated that re-establishment may occur from the parent stock or through recruitment from adjacent areas once the dredging has been completed.

From an ecological, social and economic point of view, it is important to know whether these seagrass beds will re-establish, and at what rate. As a detailed record exists as to the state of the seagrass prior to the development, it is suggested that this resource be monitored at six monthly intervals to complete our understanding of this important and largely unknown process. This process is particularly relevant due to the island nature of Fiji, where such development is common and the stability of foreshore, and maintenance of the inshore trophic balance are important. Subsistence fishing may be directly affected by the degradation of the environment.

General Water Quality

The major change observed in the general quality of the water in the study area was the high turbidity in the area to the west of the dredging site, previously covered with seagrass. Four visits were made at weekly intervals to the study sites during the present monitoring session. These revealed an increased level of turbidity as compared with previous visits in July of 1992 and in 1991. This chronic turbidity must result from resuspension, through tidal and wave action, of the large amounts of silt, newly deposited during the flood run-off and more locally from the dredging operation.

There was also a clear trend in clarity and amounts of suspended solids as one moved away from the dredging site. Offshore sites were less turbid (see Table 1). In the early EIA report (Anon., 1989), it was generally accepted that there would be increased turbidity in the vicinity of the dredging work and that regular monitoring was necessary to assess how long the problem would persist after dredging had stopped. It is therefore recommended that further monitoring be carried out on this aspect of the project.

Future Environmental Concerns

The operation of the marina presents particular environmental concerns that need to be discussed at this stage. The marina basin can either provide a sanctuary to fish and other marine life or, through pollution, the basin will become an unproductive area adversely affecting the surrounding area (Raj and Seeto, 1986).

Water clarity is one of the major concerns in the development of the marina. The proximity of the dredge spoil inter- and sub-tidally, is certain to contribute to the increased turbidity. Monitoring will provide information on degree and duration of turbidity. This is an important consideration in assessing how long the system takes to return to normal.

Another important pollutant in marinas is the compound tributyl-tin. The mooring of large numbers of vessels in confined waters will give rise to higher levels of tributyl-tin from the tin based antifoulants used here. Unlawful in Australia and New Zealand, tin based antifouling paints give rise to increased concentrations of the toxic compound tributyl-tin in the benthos and surrounding environment. In a study on levels of tributyl-tin (TBT) in sediments collected from the Suva waterfront (from Kings Wharf to Royal Suva Yacht Club), it was found that levels were extremely high near the slipways. In fact the concentrations found were some of the highest ever recorded so far (Stewart and de Mora, 1992). The other worrying discovery from this study was that imposex (the development of male characteristics in females) had occurred in most of the neogastropods collected from near the slipways. Imposex would render the female gastropods sterile and in the long run would limit survivorship of the species. As well as these problems, TBT compounds cause irritation to the skin and eyes and inhalation of aerosols leads to respiratory irritation (IPCS, 1990).

Faecal contamination of the water will occur resulting from the direct discharge from vessels. The levels of this raw sewage should be monitored to ensure that concentrations don't exceed safe limits. Other refuse such as plastics are also common pollutants in marinas.

Fuel and oil spillage are a chronic hazard in marinas. It has been shown that the soluble factions of diesel fuel are toxic to the plankton and other sea life (Nelson-Smith, 1970). This may result in a reduction of successful recruitment which may include food items such as fish or molluscs. Chronic spillage leads to a change in the nature of the living environment (Cowell,1971; Guzman et. al., 1990; Bak, 1987). Levels of hydrocarbons and the frequency of spillage should be monitored. A contingency plan should be in place to deal with large spills.

RECOMMENDATIONS :

1. An operation plan should be developed for the Denarau Marina which will mitigate against further damage to the marine environment caused by the occupation of the waterways by long and short term boat anchorages. The plan should take into account the problems mentioned above. The plan could have a positive net publicity value if properly constructed aiming to emphasise the importance of caring for the marine environment.

2. Monitoring should be carried out at six monthly intervals to determine whether the seagrass beds will re-establish. The rate and extent of re-establishment are fundamental to an understanding of the long term effects of the coastal development like that at Denarau. Since an earlier environmental assessment had recommended the protection of these seagrass beds, it is important to know if the shortcomings in the development technique will result in negligible, partial or permanent loss.

3. Water quality should be monitored in conjunction with the seagrass beds assessment.

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