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Impact of Elevated Nutrients in the Great Barrier Reef

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Great Barrier Reef Marine Park Authority

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Research and Monitoring Section

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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

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EXECUTIVE SUMMARY

Nutrient levels in inshore GBR waters are reaching levels that have caused detrimental effects to corals elsewhere, though the evidence of damage to coral communities in the Marine Park is still primarily circumstantial. Preliminary studies indicate that nutrient levels in the central GBR are almost twice as high as those in the northern more pristine waters. Whether levels of nutrients have increased in parts of the Marine Park over the past couple of decades has still not been established.

Further research is required to evaluate the actual effect on GBR coral reef biota of present levels of nutrients and the levels of nitrogen and phosphorus and exposure time required to result in both short and long term damage to coral reef communities. Appropriate research and monitoring to resolve these questions are long term and costly. In the meantime, the implications of Reef deterioration are serious and consideration must now be given to ensuring that levels of nutrients do not increase in the future due to human activities.

Sources of nutrient input into the Marine Park are many and range in volume, extent of impact, and continuity. Minor inputs such as shipping and dredging are regulated, not only by the GBRMP Act but also by the Commonwealth Environment Protection (Sea Dumping) Act 1981 and Protection of the Sea Legislation Amendment Act 1986. The latter, being the means of implementation of Annexes IV and V of the MARPOL Convention, has important implications for ports, marinas, and boat construction. Relevant information needs to be directed to those affected.

Terrestrial run-off is a major source of nutrient input to Reef waters. As the central GBR is more greatly subjected to heavy run-off, due to higher rainfall and the reef being close to the coast, management action should focus on this area. Consultation with Queensland government agencies is essential to address this challenge.

Point source discharges into the Marine Park may have serious but relatively localised effects. The scale of impact is related to the volume of nitrogen (N) and phosphorus (P) discharged, circulation characteristics of receiving waters and whether the discharge is chronic. Most major coastal urban discharges are to rivers adjacent to the Marine Park and are thus under Queensland jurisdiction. The Marine Park Authority has a clear mandate to regulate discharges directly into the Marine Park, such as discharges from island and coastal resorts and pontoons. These are identifiable and relatively controllable inputs. This paper recommends guidelines for point source waste discharge subject to consultation with appropriate Queensland government agencies.

Recommendations

1. A major long term objective is that present levels of nutrients in GBR waters not be allowed to increase through human use. Where existing levels near coral reefs are shown to be higher than those which are compatible with coral reef health or which have occurred historically, the levels should be reduced to levels which are compatible to coral reef health.

2. Attention to direct waste discharge into the Marine Park needs to be given a higher priority by appropriate government agencies and by tourist operations. It is reasonable to expect that, where necessary, upgrading of treatment facilities will be phased in over a period of time to take account of the facility cost, operator training requirements, and to provide time for feedback from monitoring programs.

3. Applications for permits to discharge waste into the Marine Park will be considered on a site specific basis, taking into account alternative methods of disposal, proximity and condition of environmentally sensitive sites, hydrodynamics, and ambient water quality.

4. Applicants for new discharges should be required to instal the equivalent of secondary treatment with provision for nutrient removal to be added at a later stage. In environmentally sensitive areas, applicants should be required to establish that the proposed treatment process and dispersion characteristics are such that ambient nutrient levels or levels compatible with reef health at such sites are not increased. If secondary treatment and use of prevention and dilution techniques do not meet established criteria, nutrient removal should be considered.

5. To accurately determine characteristics of effluent from tourist operations, all permittees will be required to monitor nitrogen and phosphorus in effluent on a fortnightly basis at their expense over the next year. Additional monitoring parameters may also be required in consultation with Queensland government agencies. Sampling will be designed to be representative taking into account peak discharges.

6. A thorough assessment of existing treatment plants which discharge into the Marine Park should be undertaken with site visits to inspect treatment plant maintenance, outfall location, and effects on adjacent sensitive sites.

SECTION ONE

STATUS REPORT

BACKGROUND AND JUSTIFICATION FOR ACTION

Increasing concern with water quality in the Great Barrier Reef Marine Park and its effects on coral reef communities has been developing for some time. In May 1984 the Great Barrier Reef Marine Park Authority (GBRMPA) sponsored a Workshop on Contaminants in Waters of the Great Barrier Reef Marine Park. The Workshop concentrated on heavy metals, polychlorinated biphenyls (PCBs) and other organochlorines, and hydrocarbons. In attempting to assign priorities to areas of further research, participants noted that sediments and nutrients were more likely to be of greater concern to the Reef than the three contaminant groups considered at that workshop. In particular, an area recommended for further research was:

> "the effects of agricultural fertilisers and other nutrients exported to the GBR from the mainland" (Dutton, 1985)

As a result, in 1987 GBRMPA held a Workshop on Nutrients in the Great Barrier Reef Region. General concern was expressed that inshore waters of the Great Barrier Reef Region appear to have nutrient levels elevated above those likely to be natural and in localised areas may be reaching an undesirable threshold: in the Cairns area (where reefs are close to the coast and the northerly flow of water concentrates nutrients), in the Townsville-Magnetic Island area (where urban sewage discharges may be reaching the inner Great Barrier Reef) and in the Whitsunday area (where there are a number of tourist resorts and intensive tourism activity in a small area with a complex water circulation pattern and high levels of suspended sediments) (Baldwin, 1988).

Green Island and Low Isles reefs, two innershelf reefs off Cairns and important tourist sites, may be showing signs of the effects of exposure to water with high nutrients and high turbidity. Green Island Reef is recovering more slowly than expected from crown-of-thorns starfish which disappeared from there 5 to 6 years ago, and has experienced a prolific growth of seagrass. Low Isles corals are showing low skeletal density and thus weakening of coral skeletons possibly related to excess phosphate.

While the Great Barrier Reef (GBR) situation may not yet be critical, Kaneohe Bay, Hawaii provides a well documented example of destruction of a coral reef from chronic nutrient and sediment stress with occasional acute stresses such as storms. This destruction occurred with nutrient levels of a similar order to those recorded in some inshore waters of the GBR Region. Studies in the GBR Aquarium have also confirmed sensitivity of corals to nutrients.

If nutrient and sediment levels increase, coral reefs, particularly those inshore, may be exposed to unacceptable levels of stress over and above natural stresses, resulting from:

. nutrients from mainland and resort waste discharges and Mariculture operations (especially of concern where adjacent to fringing reefs, and/or areas of poor water circulation)
. developments particularly those involving wetland clearing or dredging
. accelerating mainland use (involving clearing and increasing use of agricultural chemicals; mainland runoff influence extends at least 30 km offshore in many areas).

Should the Reef become degraded and develop the national and international reputation of no longer having the natural qualities which attracted people to it in the first place, Great Barrier Reef tourism and Australian tourism in general can be expected to suffer. There are many examples throughout the world where such coastal deterioration has occurred: beach degradation of Miami, Florida and Honolulu; water quality and associated benthic deterioration in the Mediterranean, Red Sea, and Caribbean.

Inbound tourism is Australia's eighth most important foreign exchange earner ($12 billion). 16% of overseas visitors visit the GBR. The value of tourism in the Great Barrier Reef Region has been increasing in real terms at the rate of 10% per annum (compared with a world-wide growth of only 2.5%) which gives it an estimated gross output of $240 million per annum in 1988 (based on Driml, 1987b).

Other important activities, users and economies may also suffer if degradation of the Reef is allowed to occur. Recreational and commercial fishing yields of the Reef and coastal waters may decline. In 1981/82, this represented a total output (in terms of gross expenditure) of $42.8 million for the former and total output (in terms of gross revenue) of $36.3 million for the latter. For comparison, in the same year, total output (in terms of gross revenue) for tourism was $73 million (Driml, 1987a).

GBRMPA has identified GBR water quality as a major issue and has initiated a major research and monitoring program: in 1988-89 25% of GBRMPA's research budget was allocated to assessing water quality issues. GBRMPA established a Water Quality Advisory Committee to determine priorities for an integrated water quality monitoring program in the GBR. Funding is being sought from a variety of sources in order to carry out monitoring on a large scale. An increasing number of developers are required to monitor impacts of their developments on the water quality and biota of the Marine Park. Data required by licence and permit conditions are available. The Queensland Department of Environment and Conservation is involved in these initiatives.

Both the Commonwealth and Queensland Governments have a commitment to the protection of the Great Barrier Reef Region as a World Heritage Area. As part of the World Heritage Area is outside the Great Barrier Reef Marine Park and as major sources of nutrient inputs are outside the Marine Park, cooperation between the Commonwealth and Queensland Governments is essential. The Great Barrier Reef Ministerial Council at its meeting on 26 April 1989 discussed the issue of deteriorating water quality and consequent harmful effects on coral reefs and endorsed the continued cooperation and coordination of research and development of standards by the Authority and Queensland Government agencies and Local Government. It was agreed that there was a mutual desire to protect the Great Barrier Reef in perpetuity and that both Governments will continue to work together towards that commitment.

As a step in pursuing the commitment, this paper reviews the status of knowledge on the effects of nutrients on the marine environment, in particular on the Great Barrier Reef. It puts into perspective the main sources of concern so that remedial action may be most appropriately and efficiently directed. Guidelines for point source waste discharge are proposed, not necessarily because point source discharges are the greatest source of concern, but rather that with many new tourist developments and revitalisations underway within the Reef Region, this issue is in urgent need of resolution.

WHY CONCERN WITH NUTRIENTS

Why are we concerned with nutrients in the GBR Region?

(a) Studies have shown the detrimental effects of enhanced nutrients in tropical marine waters.

(b) There is evidence of enhanced levels of nutrients in GBR waters.

(c) There is some initial evidence that these elevated nutrients may be related to environmental deterioration in the Great Barrier Reef Marine Park.

This Section will focus on nutrients, their effects and relative sources of input to the Marine Park. Other components often associated with nutrient discharges, suspended solids, surfactants and chlorine, also can have detrimental environmental effects. These will be addressed briefly.

DETRIMENTAL EFFECTS OF ENHANCED NUTRIENTS IN TROPICAL MARINE WATERS

Detrimental effects of sewage and in particular, elevated nutrients, on tropical environments have been recognised for some time (Smith, 1977; Kinsey and Davies, 1979; Smith et al 1981). Regions where pollution by sewage, run-off, and even groundwater discharges, of coral reefs or tropical coasts have been documented include the Red Sea (Walker and Ormond, 1982); the Caribbean (Tomascik and Sander, 1985; Rose and Risk, 1985; Lapointe and Connell, 1988); Hawaii (Smith, 1977; Smith et al, 1981; Maragos et al, 1985) and Spain (Zoffman et al, 1989).

Mangrove and Seagrass Environments

Whereas seagrass and mangrove systems appear to be less susceptible than corals to damage from nutrient enrichment resulting from sewage, significant impacts have been reported. Awareness of their sensitivity is important for health of the Marine Park.

The addition of nutrients to mangroves may be beneficial in some instances. For example, increased growth rates of the white mangrove in Florida have been reported (Saenger et al, 1983). Nevertheless, high organic loading to mangrove systems may cause anoxia and increase the turbidity to levels where the resilience and diversity of these systems is adversely affected. The disposal of excessive organic wastes can lead to defoliation and death of trees or may be deleterious to associated flora and fauna, as occurred in Puerto Rico (Hatcher et al, 1989; Saenger et al, 1983). Boto et al (1988) strongly recommended that if waste is to be discharged to a mangrove system, effluents should be subjected to preliminary treatment to reduce the organic matter content prior to discharge. It is suggested that the ability of mangroves to absorb nutrient inputs will be heavily dependent on the placement, timing, quantity and nature of the effluent. While mangrove trees and soils have a capacity to absorb fairly substantial inputs of inorganic nutrients at least in the short to medium term, their waterways contain very low levels of dissolved nutrients. Direct inputs of nutrients into these waterways could lead to rapid and substantial eutrophication particularly where tidal flushing may be limited (Boto et al 1988). Furthermore, where discharges contain significant amounts of heavy metals or other harmful wastes, toxic bioaccumulation in fish, crustaceans and molluscs, and other residents of these systems, may occur (Saenger, 1989).

While seagrass biomass may increase somewhat following mild nutrient enrichment, macroalgae dominate over seagrasses under conditions of marked eutrophication, leading to seagrass death. This effect is due to the growth of epiphytes and associated loose-lying species (eg *Ulva, Enteromorpha, Ectocarpus*) which may originate as attached epiphytes, and which derive most of their nutrients from the water column (Hatcher et al, 1989). Enhanced growth of epiphytes in nutrient-enriched water was determined to be the cause of large-scale elimination of seagrass meadows in Cockburn Sound, Western Australia and in Port Adelaide.

It has also been hypothesised that just as seagrass acts to trap sediment, when it dies silt is more easily resuspended resulting in increased turbidity. Thorhaug (1981) claims that seagrasses have an aesthetic clarifying effect on water quality, by baffling particles from turbid water and keeping sediment bound in place. This of course, is an asset in tourist locations.

Molluscs/Crustaceans

One of the obvious effects of pollution has been the reduced availability of traditional oyster and clam grounds because of shellfish contamination with bacteria and viruses from domestic sewage. At the larval stage, oysters are extremely sensitive to pollutants such as detergents, pesticides, herbicides, and metals. Sublethal effects such as poor reproductive success has also been noted in adult bivalves. Acute toxic effects on oyster larvae from chloramines has been observed in Virginia waters. Chloramines are formed when chlorine from treated sewage effluents and cooling waters reacts with nitrogenous compounds found in sewage. Chloramines are particularly toxic when mixed with seawater. Increased nitrogen levels from agricultural runoff and sewage effluent lowered oxygen levels, causing shellfish mortality offshore of New Jersey valuing $123 million in 1976 (Leonard, 1989).

A recent study by Muir et al (1989) revealed significant mortality of prawns at nitrate concentrations as low as 1 mg/l nitrate. Safe levels of nitrate for prawn larvae were not determined by the study, but it was suggested that it could be considerably lower. Thus toxic levels of nitrate may occur several kilometres from an ocean discharge point.

Case Studies: Nutrients and the Algal/Coral Relationship

A review of some case studies (Table 1) illustrating nutrient effects on reef environments is useful to gain an understanding of the complexity of impacts from nutrients, particularly on the algal-coral relationship and as warning signs to look for which indicate Reef deterioration. In reviewing these case studies, it is apparent that most obvious or extreme impacts from nutrients have occurred where nutrient input to the system is extremely high, is chronic, and/or water circulation is poor. Applicability to the Great Barrier Reef should be viewed in this context.

Enhanced growth and increased biomass of *Cladophora*, a green alga, now covers large areas of inshore waters of Bermuda although it was not reported 25 years ago. In Harrington Sound, it is reported as a dense mat covering 10 ha of the bottom (Bach and Josselyn, 1978) and averaging 10 cm in depth. It is claimed to be a result of cumulative seepage of N-rich groundwaters coupled with efficient utilisation and recycling of dissolved organo-phosphorous compounds (Lapointe and O'Connell, 1989; Bach and Josselyn, 1979). Concentrations of nitrate, nitrite and reactive phosphorus are usually all below 1 μM while ammonia levels were generally less than 3 μM. Studies also indicated that phosphorus is concentrated in the mat relative to the surface water (Bach and Josselyn, 1978).

As a result of discharge of untreated sewage to a portion of a Grand Cayman fringing reef, Rose and Risk (1985) found significantly greater dead coral substrate in the vicinity of discharge compared to a control site. It was suggested that the six-fold increase in bacteria biomass in reef waters receiving the effluent was linked to a five-fold increase in sponge (*Cliona delitrix*, a filter-feeding macroborer) biomass at the polluted site relative to a control site. The elevated density of *C. delitrix* biomass signified a similar increase in the amount of coral (*M. cavernosa*) skeleton that had been eroded by this sponge and reduced to silt-sized sediment.

Though microbial pollution indicators were acceptable in an area of treated waste discharge near San Gabriel in Alicante, Spain, levels of nutrients were very high, with resulting degradation of local marine ecology and aesthetic values. (Zoffman et al, 1989).

In the increasingly urbanised Florida Keys, *Phormidium*, the microfilamentous blue-green alga that causes black-band disease in corals, is becoming chronic on reefs, especially those adjacent to Key West. Those reefs are influenced by the discharge of 8 million gallons per day of raw sewage effluent into upstream surface waters. Black-band disease is particularly well known for its ability to rapidly erode coral cover, which then becomes overgrown by large frondose algae (Lapointe, 1989).

A survey by Veron and Kuhlman of reefs around Ishigaki Island, Japan found that nearly all reefs have been damaged or are stressed by human activity. Intensive construction has led to increased siltation of nearby reefs. Heavy use of agricultural chemicals has caused widespread eutrophication and chemicals are having sublethal effects on corals. The survey found that the amount of reef destruction varied according to the source of pollution (Kuhlman, 1988). The stages of deterioration were: in stage one, lower species diversity and coral cover; stage two, white-band disease and other infections; stage three, lower density of the more resistant corals with overgrowth by algae, zoanthids, and sponges, and increased crown-of-thorns starfish.

Localised pollution by sewage discharge and phosphate dust from ship loading of coral reef areas at Aqaba, Red Sea contributed to coral death approximately 5 times greater in the polluted area than in the control area (Walker and Ormond, 1982). Growth of algae (*Ulva lactua* and *Enteromorpha clathrata*) was greatly stimulated near the outfall but it appears that algal growth was not the direct cause of coral death. It is suggested that sediment load was increased by the sediment trapping capacity of enhanced algal growth. Phosphate levels in the sewage area were over three times those in the control area posibly reducing calcification of corals. There was no elevation in nitrate and nitrite and no analysis done for ammonia, though increased growth of *Ulva* as observed is a reliable indicator of elevated ammonia levels. In addition, the density of sea urchins, *Diadema setosum*, in the sewage area was three times that in the control area. It was concluded that coral was under stress because of the reduced light intensity, inhibition of calcification by excess phosphate and increased sediment load.

Archer (1987) reports that Barbados' offshore bank reefs remain healthy whereas the nearshore fringing reefs have been deteriorating since clearing of the virgin forest for cane plantations in the seventeenth century. This resulted in low coral cover by 1977, compared to similar reefs in the Caribbean.

Tomascik and Sander (1985) found in Barbados that growth rates of coral subjected to pollution were negatively correlated with nitrogen and phosphate. However, they concluded that reduced growth rates of corals at Barbados were a direct result of increased suspended particulate matter (SPM) brought about by increased eutrophication. It was suggested that SPM up to a certain concentration may be an energy source for corals, and that corals use the additional organic fraction of SPM to increase skeletal extension rates. At some point, depending on the coral species, optimum growth will be attained, after which reduction of growth occurs because of the negative effect of decreasing light intensity, physical smothering and reduced zooxanthallae photosynthesis. The study indicated that coral diversity declined and asexual reproduction became more common. In addition, the researchers claim that their data supported the hypothesis that short-term sediment loading or high resuspension rates of short duration do not affect coral growth rates (in terms of skeletal extension) to the same extent as low but persistent sediment loading and/or chronic turbidity.

The total phosphorus and inorganic phosphorus concentrations in skeletons of the corals *Montastrea annularis* and *Diploria strigosa* from Bermuda, St Croix in the US Virgin Islands and Curacao were shown to be larger in the polluted area than those from relatively pristine sites (Dodge et al, 1984). Polluted sites were located close to sewage outfalls on all three islands and total phosphate levels were up to twice "control" levels.

In the Great Barrier Reef Aquarium in Townsville, elevated nutrient levels have been linked with the death of corals. In 1987, the nitrate concentrations when accelerated coral death occurred in the tank were above 2.5 μM with phosphorus following closely the pattern of nitrogen. Acroporids appeared to be the most sensitive, with increased death rate ocurring when nitrate concentration was 0.8 μM. This value is a marked increase over general levels on a coral reef, but is low compared to concentrations that may be expected within the vicinity of a waste water discharge. Further, the nitrate spikes associated with coral death in the tank were short-term events lasting 3 days and higher coral mortality might ensue if elevated nutrients persisted. As the problems appeared to result from release of nutrients from disturbed sediment, the importance of the sedimentary nutrient pool and the danger of suspending sediment in a confined or restricted area must be highlighted (Morrisey, 1988). It should be noted however that the system is totally closed and periods of elevated nutrients might also be coincident with periods of elevations in other undesirable substances (Kinsey, pers.comm.).

The most comprehensive case history of sewage effects on reef communities is provided by the studies of Kaneohe Bay, Hawaii. Kaneohe Bay, in particular the poorly flushed southeast sector, was subjected to a chronic stress, receiving increasing amounts of sewage over 30 years. Most of the wastewater received secondary treatment after 1963 and by 1977 the total sewage effluent volume totalled over 20000 m^3 per day. Most of the sewage was diverted from the Bay to an ocean outfall in 1977 and 1978. The Bay has also been subjected to episodic stresses from stream run-off after heavy rain. A large amount of the community shift occurred since a major surface reef kill in 1965. Kinsey (1988) claimed that by 1977 the Bay community structure indicated a failure to recover from the 1965 kill because of well established chronic stresses. It was speculated that eutrophication and sedimentation as a result of urbanisation and construction, were the major cause of an observed decline in lagoon coral communities in the south lagoon and explosive growth of the green algae *Dictyosphaeria cavernosa*, which was smothering coral in the middle lagoon. Surveys documented changes to the lagoon before and after diversion of sewage from the lagoon. Some of the most important findings of these studies are summarised as follows.

A survey by Maragos in 1972 revealed that compared to earlier studies, 99.9% of the coral reefs in the heavily polluted southeast sector had been eliminated, as were 87% of the corals in the transitional sector and 26% in the northwest sector. The increased levels of nutrients, especially nitrogen and phosphorus, and associated food chain relationships resulted in the following changes in the community structure of the Bay:

(1) phytoplankton and zooplankton grazers increased dramatically, especially in the southeast sector.

(2) populations of benthic filter-feeders eg. sponges and zoanthids increased in response to increased food supply

(3) a sediment-feeding sea cucumber appeared in large numbers on organic rich sediments in the southeast sector

(4) the growth of benthic algae, especially the "bubble alga" *Dictyosphaeria cavernosa* was greatly stimulated

(5) corals decreased in abundance (Marsalek, 1987).

Many of the changes in response to sewage input were reversed slowly after sewage outfall was diverted offshore. Smith et al (1981) monitored the bay ecosystem response by measuring physical, chemical and biological characteristics before and after actual sewage diversion. Initial response of the ecosystem after diversion was quite rapid. Dissolved inorganic and particulate nitrogen, chorophyll and plankton biomass decreased by about 30% resulting in increased water clarity and more favourable conditions for coral growth. Within a few weeks, sponges and zoanthids began to die off in some areas. One year post-diversion, Smith reported that flora and fauna of the bay had not returned to presewage conditions, though there was a dramatic decline in *Dictyosphaeria* in the middle bay. The sea cucumber was still very abundant. There was little apparent recovery of corals at that time.

By 1983, Maragos et al (1985) found a remarkable recovery of corals, especially *Porites* and *Montipora sp.* Less common coral species showed substantial increase in abundance and distribution throughout the entire lagoon up to 10 km away from the site of major impacts. *Dictyosphaeria* had declined greatly except for a minor increase in the northern lagoon. It is expected that coral will eventually repopulate portions of the bay, although some areas will remain unavailable to coral because of changes in the originally hardbottom substrate now covered with a layer of organic rich sediment (Marszalek, 1987).

Maragos (1985) commented on the difficulty in distinguishing between the negative effects of sewage from that of sedimentation since both were concentrated in the south bay during the same time. However, as the dominant species of coral in the bay appeared to be more sensitive to sewage and more resistent to sedimentation, and because sedimentation could be only a minor factor in the decline elsewhere in the lagoon, it is suggested that the rise and fall of the volume of sewage discharged is the best explanation for most of the decline and recent recovery of lagoon corals. Corals introduced to the area also died in direct relationship with their proximity to the sewage discharge point.

Kinsey (1988) concludes that reefs may tolerate elevated nutrient levels well above the natural range for significant periods of time with the community structure not superficially reflecting the chronic nutrient stress for a long time. However, elevated nutrients will always result in suppressed community calcification resulting in decreased real growth and structural maintenance. The rate of change will be accelerated dramatically by the occurrence of an acute event, the recovery from which will clearly reflect adaptation to the chronic stressor. Recovery from such community structure modification can occur within a few years if the chronic stress is removed and if good larval input and suitable substrate are still available.

Monitoring the regrowth of coral reef communities following substantial anthropogenic degradation indicates that recovery is typically slow, in the order of years and decades, and often incomplete (Holthus, Evans and Maragos, 1986; Hatcher, Johannes, and Robertson, 1989). This contrasts with quite rapid recovery rates following many natural disturbances (Brown and Howard, 1985; Pastorak and Bilyard, 1985). One explanation is that anthropogenic perturbations tend to be chronic while natural perturbations are infrequent though occasionally severe (Kinsey, 1988; Hatcher et al, 1989).

Circulation Effects

At Davies Reef, Furnas et al (1989) found that lagoonal phytoplankton biomass and production were inversely related to wind strength. Production and biomass were highest during a mid-summer calm period when water residence times were on the order of several days, but differed little from values measured in surrounding waters during a period of high winds when the residence times were less than one day. Phytoplankton blooms develop within GBR reef lagoons during intermittent calm periods when water residence times exceed phytoplankton generation times. Water residence times can range from a single tidal cycle for a microatoll (Kinsey and Domm 1974) through to several days for a platform reef lagoon, to months for the lagoons of oceanic atolls (Furnas et al 1989).

Studies done as part of the Crown-of-Thorns Research Program found that areas of high residence often occur along the northeast or southwest corner of each reef and longer residence times will be experienced by particles which remain close to the sea bed rather than those which reside near the surface (Moran et al, 1990).

Whereas large outfalls in well flushed turbulent open-coast regions appear to have minimal impact on coral reefs (Pastorok and Bilyard, 1985), even small scale discharges, if not effectively flushed, can cause severe problems. The Kaneohe Bay situation indicates that detrimental effects of sewage on corals are generally magnified in confined embayments with restricted circulation (Maragos et al 1985). It is worth noting that the diversion of sewage away from Kanohoe Bay to the ocean outfall has had no noticeable adverse impact on the reef communities adjacent to the outfall. The site is exposed to strong currents, waves and water circulation, with residence times measured on the order of hours, preventing a build-up of nutrients and plankton biomass (Maragos et al, 1985). Studies in Alicante, Spain also indicated that the shape, structure and orientation of the coastline was a factor in determining the degree to which beaches were affected by untreated sewage (Zoffman et al, 1989). Even though enormous quantities of sewage were discharged along the Miami coast in Florida, effluents were rapidly diluted and dispersed by the adjacent Florida current once the outfall was extended to several kilometres offshore, resulting in a marked reduction in coastal pollution (Marszalek, 1987). This is contrasted with a situation reported by Johannes (1972) where seepage from a single cesspool serving a public restroom in Hanauma Bay brought about the localised degeneration of the nearby coral community. Attached algal populations were found to be larger than normal in this area, with much of the coral dead and encrusted.

In summary, then in assessing potential for impact of nutrients on the GBR, it is important to take account of the volume of nutrient input, the degree to which it is a chronic source and the dispersal and dilution characteristics of the receiving waters.

WHY NUTRIENTS IMPACT CORAL COMMUNITIES

Changes in the System

Pastorok and Bilyard (1985) note that coral reef ecosystems are extremely sensitive to environmental perturbations. This high sensitivity is linked to three factors.

(i) corals have narrow physiological tolerance ranges for environmental conditions
(ii) the interactions of key reef species eg. algal-coral competition are susceptible to pollutant stresses. Destruction of coral by pollution leads to the eventual demise of many reef species dependent on living coral for food, shelter and refuge from predators.
(iii) the effects of toxic substances may be enhanced by the high water temperatures common in coral reef environments.

Coral reefs thrive in nutrient poor conditions. Dissolved nutrient concentrations are usually much lower in tropical surface waters than in temperate waters. The elevation of phosphate concentrations by 0.75 µM in New England waters, for example would result in doubling of phosphate concentration, whereas in the eastern Caribbean it would constitute an approximately 40-fold increase. The possibility exists that the impact of a given increase in nutrient concentrations on a nutrient-poor tropical marine community might be much greater than that on a typical temperate marine community (Hatcher et al, 1989). Birkeland (1987) postulates that the pattern of nutrient availability is a major determinant of large scale differences in benthic community structure in the coastal environments of the tropics.

As illustrated by the previous case studies, long term addition of relatively small amounts of nutrients can cause major imbalances in existing coral reef communities. The growth of mat-forming, attached and planktonic algae is promoted, as are the food webs associated with those algae (Lapointe and O'Connell, 1989). An increase in filter feeders such as sea cucumbers, sponges, and zoanthids (Maragos, 1972; Smith et al, 1981; Rose and Risk, 1985) and herbivorous fish has been observed. Algae can affect coral by interfering with complex life processes which normally occur at the coral surface, by competition for light and nutrients, by shading and overgrowth (Marszalek, 1987). Breakdown of planktonic algae can add to the sedimentation load. High suspended sediment levels in the water column decrease the amount of light available to corals, reduce zooxanthallae photosynthesis and can lead to eventual physical smothering (Tomascik and Sander, 1985). Increased sediment loads on corals have also been attributed to the sediment trapping capacity of attached algae such as *Ulva lactua* and *Enteromorpha clathrata* (Walker and Ormond, 1982). Progressive dominance by soft benthic algae may further decrease suitable hard substrate sites available for coral colonisation (Kinsey and Davies, 1979). An increase in boring sponges and worms can provide an additional threat to coral. Thus a decrease in coral cover, taxonomic richness and net calcification as a result of nutrient enrichment has been reported by many authors (Kinsey and Davies, 1979; Smith et al, 1981; Walker and Ormond, 1982). A general reduction in numbers of predator fishes may be related to the absence of living corals and reduced habitat complexity (Smith et al, 1981).

Shinn (1989) claims that corals are remarkably resistant to suspended sediments when unaccompanied by the additional stress of excess nutrients or extreme temperature fluctuations. When over-fertilized, rapidly growing blue-green algae, fungi, and bacteria, normally held in check by herbivorous fishes and sea urchins, out compete the corals.

Coral Calcification

There is increasing evidence that coral growth and calcification are negatively affected by enhanced phosphorus. Environmental factors which influence calcification in coral are light, temperature, salinity, suspended sediment, nutrient availability and sexual activity (production of gametes diminishes energy available for growth and calcification).

Simkiss (1974) claimed that phosphates were crystal poisons of calcification, influencing deposition of calcium in animals with calcareous skeletons. He showed that phosphate inhibits the precipitation of calcium carbonate from artificial seawater at concentrations as low as 10 μM (Brown, Ducker, and Rowan, 1977). In relation to coral, Simkiss (1964) suggests that though the role of symbiotic zooxanthellae in the coral tissues in influencing calcification is unknown, their beneficial effects may be related to the removal of phosphates as inhibitors of calcification (Brown and Scoffin, 1986). In fact, in contrast to the response to nitrogen, several biochemical characteristics suggest that zooxanthellae freshly isolated from corals have high levels of the phosphate uptake system and levels of phosphatase that are typical of the P-starved algae (Yellowlees et al, 1988).

Kinsey and Domm (1974) tested the effects of discontinuous fertilisation of a lagoon patch reef system at One Tree Island, Great Barrier Reef. Enough phosphate was added to maintain 2 μM during a three hour period, an increase of 10-fold over that normally found in the area. N was added to maintain 20 μM urea and ammonium, compared to normal N in the area of less than .5 μM nitrate. The results of Kinsey and Davies (1979) revealed a pronounced increase of about 50% in the rate of net community photosynthesis over that for any equivalent period of the preceding year. The increase was attributed solely to increased production by benthic algae, as tidal washout prevented any appreciable buildup of phytoplankton. A greater than 50% suppression of reef calcification was found in the fertilised area, compared to control corals in the unfertilised areas, attributable to the phosphate (Kinsey and Davies, 1979).

The authors also commented that the highest phosphate level reported in the Pacific, 0.6 μM, at Canton Atoll (as per Smith and Jokiel, 1975) was associated with the lowest overall lagoonal calcification rate (as per Smith and Kinsey, 1976).

Brown et al (1977) found that the growth of articulated coralline algae is signficantly inhibited by a medium enriched with orthophosphate (30 umol/l) at a concentration normally used in culturing other groups of marine algae. When concentrations of 7.5 and 3.8 μM were used, significant increases in survival and growth were found in coralline algal cultures. Coralline algae are widely distributed from tropical to polar seas.

Suspended solids, surfactants, and chlorine

Frequently suspended solids, surfactants, and chlorine are found in association with nutrients. Though data is limited on the effects of these water quality parameters on coral reef ecosystems, the possibility of a confounding effect on the environment must not be ignored.

Suspended particles in waters of the Great Barrier Reef consist partly of fine inorganic sediments entrained in the water column by turbulence, and partly of particles of organic origin such as detritus, phytoplankton and micro-zooplankton (Bell et al 1987b). Sources can be terrestrial run-off, dredging, storms, and sewage. Sedimentation itself has negative effects on coral by: increasing turbidity, thus reducing photosynthesis; resting on the polyp surface which causes stress through sediment rejection mechanisms such as mucous generation; inhibiting population recruitment; and smothering corals (Pastorak and Bilyard, 1985). Though sedimentation effects on the reef ecosystem needs to be given separate attention, this paper briefly addresses sediments only as they relate to nutrients. Suspended solids in receiving waters for sewage discharges originate from three sources: particles contained in effluents, particulate organic matter produced by nutrient enrichment, and natural seston. The relative importance of these depends on wastewater treatment levels (Bell et al 1987b).

McConchie (1988) discusses transport of nutrients through adsorption onto colloidal particles (in this case, primarily fine particles of clays and iron-oxides in water) and subsequent desorption in response to changes in environmental conditions. Since phosphorus adheres to clay particles, increased erosion from agricultural areas where chemical fertilisers are used, can contribute to the nutrient load, though this is likely to be mainly restricted to the nearshore zone.

Detergents are actually mixtures containing surfactants plus other substances called builders that enhance the cleansing action (such as sodium tripolyphosphate), bleaching agents, fluorescers, etc. (Bell et al, 1987b). Evidence of the presence of surfactants is often observed as foam or scum around outfalls. Surfactants (surface active agents) present in detergents as well as in dispersants can have deleterious effects on marine systems, particularly fish, crustaceans, and corals.

Chlorine is commonly used as a disinfectant for sewage water and an anti-fouling agent for power-generating and desalination plant cooling water systems. The effect of free residual chlorine on many marine organisms is unclear. Unchlorinated domestic sewage has been found to be a relatively weak inhibitor of external fertilisation in marine invertebrates, but chlorinated sewage was a potent spermicide, active in inhibiting fertilisation at levels as low as 0.05 ppm (Bell et al, 1987b, as per Muchmore et al, 1973). Evidence of the effect of chlorine on coral colonies comes from the Bahamas where chlorine bleach used to hunt fish has inadvertently spilled on coral causing infection and coral mortality (Bell et al, 1987b).

Nutrients and Crown-of-thorns Starfish (COT or *Acanthaster planci*)

Some of the previous case studies have described a relationship between enhanced nutrient levels and certain invertebrates, such as seacucumbers and echinoderms, in particular *Diadema sp*. Though no such direct relationship has been found between nutrient levels and crown-of-thorns starfish, one of the many hypotheses concerning the causes of *A. planci* outbreaks relates increased terrestrial runoff and possibly enhanced nutrients to increased survival of *A. planci* larvae. Neither the "larval recruitment" hypothesis or the "terrestrial run-off" hypothesis have been totally accepted or rejected. Limitations on current knowledge of the population biology of *A. planci* and related areas require that conclusions must await further research. In all likelihood, COT outbreaks are a result of a combination of contributing factors, both natural and human induced.

The following is a brief synthesis of theories related to elevated nutrients and *A. planci*. For a more detailed discussion and critical appraisal of the above-mentioned hypotheses and others, it is suggested that the reader refer to Moran (1988). These hypotheses are discussed here as they have provided some of the incentive for research into nutrients on the GBR, and because future research and management action regarding nutrients should not disregard the potential implications of these hypotheses.

Both the "Larval Recruitment Hypotheses" and "Terrestrial Run-off Hypotheses" are based on the postulation by Birkeland (1982) that large fluctuations in the abundance of

A. planci are the result of differential survival of larvae rather than of any other stage of the life cycle. He argued that outbreaks arise from periods of successful recruitment, not from a decrease of predator pressure which would result in the gradual build-up of individuals over a number of years. Examination of existing data on *A. planci* strongly supports the idea that population outbreaks result from years of high recruitment success (Olson, 1987). Lucas (1975) suggested the following factors may be important in affecting the survival of larvae and early juvenile stages: degree of fertilisation, abundance of food, temperature, salinity, extent of predation, dispersal and availability of suitable substrata for settlement.

The Larval Recruitment hypothesis proposes that recruitment of larvae of *A. planci* is enhanced during times of favourable environmental conditions (Moran, 1988). This was based on laboratory studies by Lucas (1973, 1975) which indicated that the survival of larvae is improved under conditions of lowered salinity (about 30%) and higher temperatures (28° to 32C°). He hypothesised that a slight alteration in the survival rate of larvae could lead to large increases in the number of individuals that settle and this may result in population outbreaks in later years.

The Terrestrial Runoff Hypothesis suggests that nutrients in run-off from high islands and continental land masses cause phytoplankton blooms which act as a food source from *A. planci* larvae, thus promoting their survival (Moran, 1988). Lucas (1982) found that food availability was important in determining the survival of larvae. He suggested that natural levels of phytoplankton normally found on the GBR were insufficient for the survival and development of *A. planci*. Lucas used chlorophyll a as a measure of phytoplankton biomass and compared his results with concentrations in the field. Phytoplankton productivity in coral reef areas is generally considered low, but it is not clear whether these conditions could cause mass larval starvation. Olson (1987) found little difference in survivorship and development between *A. planci* larvae cultured in natural sea water compared with those raised under conditions enriched by a certain phytoplankton (*D. primolecta*).

Bacteria, dissolved organic matter (DOM), detritus and nonphotosynthetic plankton are all potential food sources, which are not quantified by Chlorophyll a. Many invertebrate larvae have been shown to be capable of substantial rates of DOM uptake (Olson, 1987). Manahan et al (1983) suggested that the larvae of an echinoid could obtain up to 79% of their energetic needs from uptake of DOM. Rivikin et al (1986) have shown that bacteria may be a major source of nutrition for the larvae of some Anarctic asteroids. Very little is known about the nutritional importance of these food sources to the larvae of *A. planci* or their abundance in coral reef waters.

Spawning of *A. planci* is concentrated between November and February in the Southern Hemisphere at the time of heaviest rainfall. In the larval stage which is though to be spent near surface, *A. planci* feeds on unicellular algae. After settlement on a suitable substrate, within a month of spawning, the juvenile feeds on encrusting and epiphytic algae for about 6 months. From this point on, *A. planci* prefers and grows fastest on coral but will feed on algae or other foods.

Birkeland (1982) correlated rainfall data with information on outbreaks in Polynesia and Micronesia finding that the sudden appearance of primary outbreaks of *A. planci* follow some three years after periods of heavy rainfall during the spawning season, which have also followed times of drought. He found that outbreaks occurred after wet typhoons bringing heavy rain, not after dry typhoons. He hypothesised that terrestrial runoff from heavy rains may provide enough nutrients to stimulate phytoplankton blooms of sufficient size to produce enough food for the larvae. Larvae appear to be adapted to relatively low salinities in which ample nourishment occurs. In fact a combination of environmental conditions may actually stimulate *A. planci* spawning.

The conditions described above, lower salinity, higher temperatures and higher nutrients may occur within 50 km of the North Australian coast, particularly between Ingham and Mossman, where there is high rainy season precipitation combined with numerous rivers to produce intense periods of heavy run-off. The Reef is close to the mainland along this section of the coast thus providing the ideal habitat for adult *A. planci*. The initial waves of *A. planci* outbreaks on the GBR coincided with this geographic area, with the main effects concentrated in the region between Lizard Island and the reefs off Bowen (Moran, 1988). Nearly all of the outbreaks which have occurred in the Indo-Pacific region have occurred on reefs near high islands or mainland continents (Birkeland, 1982). In fact, according to Birkeland, people from high islands remember previous outbreaks, have traditional cures for punctures and have specific names for *A. planci* whereas people from atolls do not.

Marsh (1977) found that phytoplankton blooms around Guam were associated with availability of nitrate-nitrogen and reactive phsophorus. His values for nitrate-nitrogen levels around Guam were over an order of magnitude higher than those found by Webb et al around Enewetak, an atoll.

This theory implies that the frequency of occurrence of processes favouring COT recruitment may have increased indirectly by man's activities, as the development of adjacent land could have led to increased run-off and higher nutrient loads. With increased land clearing since the 1920's and a peak in use of fertilisers in the hinterland adjacent to the GBR in the 1960's, increased terrestrial runoff are carrying heavier than "natural" loads of organic nutrients due to use of agricultural chemicals. Valentine's study (1988) explained that fertiliser application occurs just prior to or during the rainy season leading to relatively high flushing of nutrients out through drainage systems, particularly in a dissolved form, relatively available for uptake.

Another human perturbation that may contribute to *A. planci* outbreaks, but has been given little attention, is trawling. Trawling is known to intensely modify the bottom community and to stir up the bottom sediments. Little is known about which surfaces are preferable for *A. planci* larval settlement. Though it is felt that it would be an advantage for larvae to settle on coralline algae, Lucas found that larvae will settle on any biological film. In addition, in altering the bottom community where *A. planci* larvae settle, trawling also may selectively remove certain predators of juvenile *A. planci*. For example, the painted shrimp, *Hymenocera picta*, was found to contribute to limiting the abundance of *A. planci* on lower fore-reef slopes in Panama producing a decrease in the rate of coral mortality in the area (Glynn, 1982, 1984). Mathematical models of starfish dynamics indicate that outbreaks can arise from small changes in the mortality of adult and juvenile starfish and that major fluctuation in adult densities can be caused by processes that affect larval mortality (Moran, 1990). Resuspension of sediments from trawling may also remobilise nutrients which could provide a food source during this early critical stage of life.

EVIDENCE OF ENHANCED NUTRIENTS IN THE GBR

Green Island

Green Island has a history of human occupation dating back to the late nineteenth century. Tourism visitation has increased dramatically since 1956, making it the most highly visited location on the Great Barrier Reef (approx. 120,000 per year). Its attractions include a resort, marine zoological garden, underwater observatory, sandy beach, and reef viewing.

Nutrient input to the reef occurs from untreated sewage discharge from the resort and public toilets at an estimated mean discharge rate of 100 m^3/day (Bell, 1987) through an outfall at the reef edge to the southwest of the cay. Water inlet and outlet pipes for Marineland Melanesia aquarium lie on the reef flat to the north of the cay (Steven et al 1989). Groundwater is also contaminated from septic tanks and the reef lies within the discharge plume of the Barron River.

A combination of natural and anthropogenic disturbances of the reef has resulted in a marked increase in the seagrass biomass to the north-west of the cay and a decrease in hard coral cover. Beach replenishment programs and revetments intended to reduce erosion around the western end of the cay have led to an unnatural redistribution of sediments in this area. Two infestations of crown-of-thorns starfish, *Acanthaster planci*, have been recorded twice (1962-67, 1979-89) in the past three decades, greatly reducing hard coral cover. In fact, each outbreak of the starfish on the GBR was first reported at Green Island Reef. Recovery in the form of diverse assemblages of *Acropora sp* had been observed along the south-west and north-east slopes by 1989. (Van Woesik and Fisk, pers. comm.).

Relevant findings of studies of Green Island reef, funded by the Marine Park Authority, are discussed.

The area of seagrass beds at Green Island reef has increased markedly over the last four decades, particularly on the inshore flat to the north and north-west of the cay. Though less apparent in air photographs, seagrasses are also widespread over the reef flat to the south of the cay. Through photographic interpretation, Kuchler (1978) estimated the area of seagrass to be 0.09ha in 1945, 1.5 ha in 1959, 3.9 ha in 1972, and 13.6 ha in 1987. This increase was possibly a consequence of the discharge of nutrient rich waste water from the Island which has generally taken place over the southern or south-western edge of the reef. Following discussions with long-term residents of the island, which revealed that the sewage outlet had once been to the north, Kuchler unearthed effluent particles stored in the upper 20 cm of sediment on the northern sand flat where seagrass was established (Baxter, 1987). The increase in seagrass beds and their apparent health, could be attributed to moderate addition of nutrients. Baxter (1988) found epiphytic algal cover on seagrasses in some of his transects, on the north, north-west of the cay, indicating a sufficient nutrient supply.

Another possible contributing factor to the expansion of the seagrass beds may have been the redistribution of the fine sediment used in beach replenishment programs in 1973 and 1975. During winter, the prevailing south-easterly currents carried the sediment from the unprotected south-western beach to the north-west of the cay where it was deposited, providing an excellent substrate for seagrass colonisation (Baxter, 1987).

Rasmussen (1988b) found that strontium levels recorded in the skeletons of corals provide an accurate interpretation of environmental changes. A direct relationship exists between enhanced levels of phosphate $(PO)_4$ in the marine environment and strontium concentrations precipitated into the coral skeleton. It was found that phosphatic type fertilizers have a deleterious effect on skeletal deposition, leading to increased fragility of the coral colony.

Limited use of phosphatic type fertilizers in the Cairns hinterland prior to 1939 correlates with levels of strontium in *Porites* at Low Isles and Green Island. Likewise examination of coral cores from Green Island and Low Isles indicates a correlation between skeletal density and increasing fertilizer use in the hinterland since the 1960's (Valentine, 1988; Rasmussen, 1988b).

Allan and Johns (1989) study of sediments at Green Island suggest that terrestrial input from the mainland would not appear to be significant however local anthropogenic input is apparent, in the form of human sewage and hydrocarbons indicative of petroliferous input. They were found to be localised to the areas of release and levels were low. The biomarker coprostanol, unique to human sewage wastes was found near the outfall from the present sewage pipeline, but in none of the other sites sampled. It is suggested that the tides and currents were dispersing the waste away from the southern and western margins of the island. They concluded that it is probable that the combination of the coarseness of the coralline sediment, the light and oxicity of the waters and the oxidising conditions in the sediments resulted in the organic content of sediments being low and therefore they may not truly reflect the levels of inputs. It was suggested that *E. Coli* bacterial counts along the inter-tidal zones of the northern shorelines could provide a valuable confirmatory assessment.

Phosphorus analyses of sediments suggested that in one part only, the main beach seagrass beds, there are higher levels. This may be due to the inlet/outlet pipes for the aquaria.

Evidence of petroleum products from boat traffic were clear from several indicators. The strongest indicator and perhaps the more disturbing marker due to its resistance to degradation is that described as unresolved complex material (UCM) present in samples taken from the jetty and further around the island, suggesting movement of exhaust hydrocarbons being released into the water column and accumulation in a westerly-northerly arc around the island.

The active reworking of finer-grained sediment by *Callianassa* was observed to be significant in the observed bioturbation of Green Island sediments (Allen and Johns, 1989). Rapid dispersion, mixing and microbial activity may be removing these components from the sediments. It is possible that they are accumulating in the biota rather than the sediments.

Preliminary studies have been undertaken on hydrodynamics and water quality around Green Island reef. Data suggests that currents around Green Island are predominantly dependent on wind direction and velocity. During north-east winds (November-December pattern), in calm weather the sewage plume would not disperse much but the main currents spiral, in an anticlockwise direction, across the western reef edge around the island onto the southern reef flat, resulting in an areas of high retention (Wolanski, pers. comm., 1988, Van Woesik, 1990). During south-east winds predominant currents over the northern reef flat are from west to east a significant portion of the time. This current transports wave-resuspended sand and other sediment from west to east, possibly pulling some sewage over the swimming area and depleting the sediment on the western reef and accumulating it far on the eastern reef flat past the swimming area (Wolanski, pers. comm., 1988). Van Woesik (1990) found high retention areas located in the lee of the island. The reef flat and slope to the north of the discharge point are continually exposed to the discharge plume. During moderate winds, the major concentration of the effluent plume disperses along the reef edge, past the end of the jetty, and off the reef into deeper waters. Considerable concentrations were retained within the lee of the island for a period of up to 18 hours.

A pilot study to determine ambient water quality around Green Island Reef indicated that no significant change in ambient nutrient levels could be attributed to sewage discharge at 250 metres from the outfall, although phosphate levels were higher in the vicinity of the outfall. Values of most of the parameters measured were generally in the range of values reported from other studies on the GBR (Steven et al, 1989). Levels of DIN and chlorophyll were found to be approaching those found in Kaneohe Bay prior to sewage diversion and in the Barbados study (Furnas, pers. comm.) and are indicative of regional nutrient enrichment. It has been suggested that localised impacts from Green Island sewage discharge may be less important at the reef scale than impacts from long-term chronic eutrophication of the inner shelf.

Hayman Island

Hayman Island in the Whitsunday group of the GBR, has been the location of a tourist resort since 1950. The resort was redeveloped recently, with a secondary treatment plant installed in 1981 and a marina dredged in 1985. Effluent is discharged at 5 m below LWD. Treated sewage is used for irrigation to the greatest extent possible with the result that during the rainy season more than 60% of the effluent is estimated to be discharged into the sea (Steven and Van Woesik, 1990). The resort has accommodation for 220 people.

Steven and Van Woesik's (1990) benthic surveys at Hayman Island indicated that there was a significant increase in total coral (hard and soft) abundance at most sites from 1986 to 1988, presumably in response to recovery from the marine dredging. Of scleractinian coral colonies, increases were greatest in the families of *Faviidea, Acroporidae* and *Poritidae.* Community composition shifted during this period towards that of the control site in Blue Pool Bay which would not have been affected by the marina construction.

It was however, found that there was significantly less coral and fish diversity and abundance in the vicinity of the resort sewage discharge, compared to control sites, in spite of the fact that waste water discharge was well within the limits set on the resort discharge license for secondary treated sewage. Near the waste discharge was also found the greatest turnover of coral species and minimal recruitment in terms of the smallest portion of taxa which had increased. It is suggested that this indicates instability and a potentially extended recovery period for those corals in the vicinity of the discharge.

Though sample sizes were low, it is interesting that of six coral cores taken of *Porites lutea*, florescence analytical techniques indicated that the one in the vicinity of the sewage outlet grew significantly faster than elsewhere. Phosphate concentration in the vicinity of the sewage outlet was at levels (0.6μM) recorded to have decreased calcification elsewhere (Smith and Jokiel, 1975; Smith and Kinsey, 1976). However this pattern of higher growth corresponds to findings of Tomascik and Sanders (1982) regarding growth of corals under moderately enhanced nutrient conditions.

Water quality and dye studies revealed high concentrations of all nutrient species at a sampling station along the reef crest with an increase in nitrate to 24 times background; ammonium to 12 times background; and reactive phosphate to 1.4 times background concentration levels. As there was an algal bloom in the vicinity at the time of sampling, it is not known if these levels are typical. The appearance of dye in the marina was disturbing as the desalination inlet is located in the marina. Water quality measurements indicated that nitrate concentrations were similar to background levels though chlorophyll a was highest in the marina.

NUTRIENT LEVELS IN THE GBR COMPARED TO OTHER REEFAL ENVIRONMENTS

Levels of nutrients in GBR waters are naturally higher than those found in the Caribbean. For example background ocean levels of reactive phosphorus in the Central GBR are 0.16 µM compared to 0.03 µM for the Carribbean and correspond with those for the Pacific Ocean around Kaneohe Bay (0.13 µM). However the fact that levels of nutrients in inshore waters of the GBR are similar to those reported for impacted regions of both the Pacific and Caribbean gives cause for concern regarding any additional increases in nutrients (Tables 2 and 3).

The data for Kaneohe Bay indicate that levels of reactive phosphorus (P -PO$_4$) of 0.33 µM with nitrate levels of 0.4 µM can lead to serious eutrophication problems. In Barbados P-PO$_4$levels of around 0.2 µM also appear to be troublesome, with nitrate levels ranging from 0.4 - 4.4 µM.

Recent preliminary work undertaken by Furnas et al (1988) suggested that phosphate concentrations in waters of the Whitsunday group and near Lizard Island (0.21 µM) are higher than in open shelf waters of the GBR and in Torres Strait (mean 0.11 µM). Preliminary measurements at Green Island indicated that nitrite was higher than in the Whitsundays but consistent with figures around Magnetic Island. Phosphate levels were similar to the Whitsundays.

Bell et al (1987) suggest that on the basis of calcification rates alone it would seem that any significant increase in the average background level of phosphorus (0.16 µM P-PO4 in mid shelf waters of the central GBR (Furnas et al,1988)) would lead to significant decreases in calcification rates.

In summary, levels of nutrients in the Central GBR are high compared to the more pristine northern GBR waters and are approaching levels which have caused environmental degradation elsewhere.

The next two sections of the report provide a basis for management of nutrient inputs into the Marine Park.

A RELATIVE PERSPECTIVE OF EXISTING NUTRIENT INPUTS INTO THE GBR REGION

There is a number of existing sources of nutrient input into GBR waters, some natural, some human-enhanced involving different volumes and varying scale of effects:

- point source discharges from island resorts, fixed structures and from urban areas adjacent to the GBR

- mainland rivers adjacent to the GBR Region and runoff from the mainland
- upwellings of nutrient enriched water at the shelf edge
- minor inputs
    - run-off from islands (non-point discharge)
    - ports and marinas
    - ships, charter vessels and private pleasure craft
    - disposal of biodegradable waste; fish-feeding
- sediment resuspension

Point Source Discharges

Waste discharge from GBR resorts is mainly of significance on a local scale as a long-term constant input to adjacent reefs. Table 4 indicates the estimation of relative input of nitrogen and phosphorus from resort effluent into the Marine Park.

Information relating to point source nutrient loading is relatively easily obtained. Loading per unit area tends to be high in limited areas, and is therefore of very high quantitative and biological significance on a local scale. Annual loading from a 3000 person discharge is approximately 2.1 tonnes P and 7.9 tonnes N, assuming 240 litres per person per day and P and N concentrations of 7 and 30 mg/l respectively if secondary treatment is provided. This may represent an atypical discharge, as most resorts discharging into the GBR average a much lower visitor population, and receiving water residence times and type of sewage treatment would have to be taken into account. An example of the effluent variability from source point discharges is illustrated by analysis of effluent from Green Island. The Island would average approximately 1000 visitors per day. In early 1988, over a period of several days the effluent measured 38 to 93 mg/l total nitrogen, 28 to 79 mg/l ammonia, and 6 to 13 mg/l total phosphorus, considerably higher figures than averages listed above though not unusual for untreated effluent. The point to stress here is that nutrients are immediately available for biological assimilation. Consequently a local productivity response may occur (Cosser, 1988b; Kinsey and Davies, 1979; Kinsey and Domm, 1974).

Fixed structures such as floating hotels and pontoons at tourist reef destinations are a recent addition to the GBR scene. The permit for operation of John Brewer Reef floating hotel (200 rooms) required secondary treatment of sewage plus ultraviolet radiation, then disposal of treated effluent by barge several kilometres to sea out off John Brewer Reef lagoon. Pontoons are discussed in more detail under minor inputs.

For comparison, and of greater concern for the GBR waters in general, is the estimated input from point source discharges from coastal urban centres (Table 5). Yet, relative to total regional loading, point-source discharges are quantitatively insignificant.

River Input

In regions with significant rainfall and especially seasonal or episodic rainfall events, the total annual loads from run-off can greatly exceed those from the discharge of sewage effluent. A majority of this may be natural but is not currently quantifiable. To put the influence of urban discharge in perspective relative to river input in general, Tables 6 and 7 indicate the order of magnitude increase in N and P.

Although attenuation of nutrient load occurs with distance from the source river, riverine phosphorus load is of high quantitative significance on a regional scale. A high proportion of total annual outflow occurs during a relatively small percentage of time, in association with major flood events. It is estimated that more than 80% of the annual discharge of rivers draining to the GBR region occurs in less than 15% of the year. Approximately 90% of annual phosphorus loading may occur in association with several major storm events between the months of January and April (Cosser, 1988b).

Valentine (1988) found that in the Barron River catchment, an amount of 2,056 tonnes of elemental N, 734 tonnes of P and 971 tonnes of K was applied to the catchment in the 1986/87 season as fertiliser. Historical data from annual ABS surveys show a dramatic increase in the use of fertilisers within part of the catchment beginning in the decade of the 1960's and peaking in 1974. Interviews with farmers established that the timing of most fertiliser applications either coincides with or immediately follows the major early rainfalls of the wet season (November to February). This is likely to produce brief periods of quick flow in which a high volume of nutrients may be transported in pulses in suspension or solution. Phosphorus is an element which is known to be transported primarily during runoff events and in particulate form associated with clay or organic material. Given these circumstances, it is reasonable to expect that the magnitude of phosphorus transported to the marine environment in streams would be underestimated if measured by periodic fixed interval sampling. Sampling programs should be designed around major run-off events.

A study by Hill (1988) indicated that a large sediment load derived from caneland catchments in the South Johnston River drainage basin is carried into the creek drainage lines where substantial deposition of coarse grained material occurs. The finer grains of silt and clay size material appear to be transported into the river which flushes the majority of it into the estuary and ultimately out to sea. The presence of phosphorus in readily measurable quantities in clay material presents a mechanism for the transport and slow release of possibly large amounts of phosphorus into the coastal environment. Further work is required to quantify this source.

Prove (pers. comm) has found that 80% of the total sloping caneland area in the "wet" coast (Ingham to Mossman) will be farmed under conservation management practices (i.e. zero tillage in ratoon, retention of residues after burning) in the 1989 harvest. Increasingly since 1982 but primarily in the last three years, such conservation practices have been consistently implemented in areas of high erodibility. Given that phosphorus attaches to soil particles and nitrogen is more soluble than P, with implemention of conservation farming practices reducing erosion, the net effect is expected to be a reduction of P in runoff and little change in N.

Although riverine input on the north-east coast of Australia is episodic, the processes of sedimentation and resuspension serve to distribute biologically available nutrients, particularly phosphorus, throughout the year (Cosser, 1988a).

Cosser (1988a) estimated mean phosphorus input for storm flow from the mainland to the Cairns Section of the Reef as approximately 9400 tonnes (standard deviation 4,700 tonnes) (Table 7). These estimates probably represent in the order of 90% of the total annual load. The distribution of terrigenous sediments in the Cairns region of the Lagoon indicates dispersion across the width of the Lagoon (Wolanski et al, 1986; Johns, 1988).

Oceanic Intrusions

Cosser (1988b) compares mainland input of 9400 tonnes with the annual phosphorus loading associated with intrusion of nutrient enriched water in the same region, calculated at 153.4 tonnes. This estimate is based on a concentration of 0.3 µM PO_4 and flow volumes as given by Wolanski et al (1988). While masses are only approximate, the relative magnitudes of the different loads, 153 vs 9400, is evident. Though levels of nutrients in an oceanic intrusion are quite variable and diminish rapidly, a typical level of ammonia is 1-2 µM and P could be as high as 0.5 µM. As the nutrients are utilized quickly, the most effective way of measuring such events is through chlorophyll a levels.

It is suggested by Pastorak and Bilyard (1985) that in upwelling areas such as the east Pacific, moderate sewage inputs may be less likely to cause dramatic changes since reef biota are already adapted to nutrient perturbations.

Groundwater Inputs

Nutrient rich groundwaters have been considered to be implicated in the demise of coastal environments in Bermuda (Lapointe and O'Connell 1989), Hawaii (Johannes, 1972) and Tonga (Zann, 1988). The slow subsurface velocities of groundwater on the coast suggest that long lag periods on the order of years or tens of years may separate early stages of groundwater contamination with recognisable ecological changes in coastal ecosystems (Lapointe and Connell, 1988). There have been few studies of through-reef water movement. A study by Oberdorfer and Buddemeier (1986) referred to by Parnell (1987) found horizontal velocities in the Holocene reef framework on Davies Reef of between 0.2 and 400 m/day. Using direct tracing methods by injecting dye into the reef framework, Parnell (1987) measured movement through the reef at Pioneer Bay, Orpheus Island. For sites seaward of the injection hole, velocities were in the range of 30-50 m/day. Velocities calculated by direct tracing methods are likely to represent only water travelling through fissures or high permeability sediment, with velocities for bulk water flow being lower. Downward movement is found to be more significant than upward movement in the reef framework and although it has not been tested, it is likely that some water from within the framework reappears at the reef front (Parnell, 1987). This has implications for septic disposal on coral cays, high islands with fringing reefs, and coastal areas.

Presently at both Green and Heron Islands, coral cays on the GBR, some of the lessees dispose of effluent directly into the subsurface. At the former, disposal is through septic tanks; the latter through an absorption trench. It has been known that groundwater at Green Island has been "contaminated" for some years but whether this itself has affected the reef environment has not yet been explored. Present lessees on Green Island have been asked to join a new sewage treatment system.

Minor Inputs

Approximately sixteen pontoons are presently located in the GBR Marine Park serving as tourist destinations, on outer or mid-shelf reefs. As the operational procedures of these pontoons involves berthing a large catamaran alongside the pontoon, toilet facilities with associated holding tanks are usually available on the vessels rather than the pontoons. However, at present there is a permit application under consideration for a pontoon/fixed structure which will require sewage treatment facilities and no sewage discharge into the Marine Park. Specific regard needs to be had to nutrient levels generated, as all of the fixed structures are located or proposed to be located on mid to outer shelf reefs where corals are unaccustomed to enhanced nutrient loads.

Elevated nutrients have been recorded at Agincourt Reef, an outer reef which is the site of a 300 person per day tourist operation. Whether these high levels are due to a natural oceanic intrusion; high nutrient input due to fish feeding and large numbers of people in the water; or a sampling error, is still not clear. Further monitoring is required (Richards, 1989).

It is estimated that the average human excretes 30 g urea each day in urine. At 5 g urea per event, 2333 mg N or 167,000 µmole N is produced. At this rate, even apparently low impact small scale operations such as private boat use have the potential to affect local water quality, particularly in marinas, sheltered bays, or in shallow reef lagoons or backreefs. It is estimated that the above amounts are sufficient to raise nitrogen to 1 µM N (that is, to approximately 10 times ambient ocean levels) in 200 m^3 or 200 tonnes of seawater. This is equivalent to 8 m x 8 m x 3 m. (Kinsey, pers. comm.). These estimates do not take account of residence time of the seawater which may vary according to location, currents, tides, and winds, however exposure of marine life to nutrients even for a couple of hours may be sufficient for maximum uptake of nutrients. (Kinsey and Domm, 1974).

The number of charter boats operating in the GBR region in 1988 was estimated at 240 (Driml, pers.comm.). Though the majority of these vessels have holding tanks, at present they are legally allowed to discharge sewage waste if more than 500 m from a reef edge. Under the Low Isles Management Plan, charter vessels visiting that reef are not permitted to discharge waste within one kilometre of the reef edge. Along with passenger liners, the input from these vessels, though not significant quantitatively on the scale of the whole GBR, may have localised impacts.

Small pleasure craft visiting the GBR were estimated to number 21,093 in 1988 (extrapolated from Hundloe, 1985). As few of these have holding tanks, in some popular anchorages, water quality can become (at least) temporarily diminished, possibly leading to a local recreation management problem. No study of the effects of this localised nutrient enhancement on biota has been undertaken at popular anchorages in the Great Barrier Reef.

Fish feeding is part of visitor entertainment at a number of resorts and pontoons. As an example of an extreme case, it was estimated that 47 tonnes of bread and food scrap were fed to fish by all tourist operators combined at Green Island in 1987 (T Stevens pers.comm.). It is expected that this also may contribute to local enhanced nutrient levels.

Sediment Resuspension

Resuspension of sediments is known to be a source of mobilisation of nutrients. One of the most critical problems, according to Morton (1977), are the changes in the chemistry of the sediments and overlying water at dredging and disposal sites that are likely to result from remobilisation during dredging and dumping, especially if the dredged sediments have a high organic content or are contaminated. Several interacting factors or processes are believed to control the flux of contaminants across the sediment-water interface: the sediment's clay fraction and organic content, redox potential, pH, bacteria, the sulphur cycle, and the iron cycle. Calculations by Ullman and Sandstrom (1987) predict the resuspension of 1 cm of GBR inshore sediment would lead to moderate increases in water column nutrient concentrations, particularly for nitrogen species. However, no simulation experiments have been conducted to test this hypothesis (Alongi, 1988).

Most major ports and harbours adjacent to the Marine Park undertake at least yearly if not twice yearly dredging of their entrance channels. In addition, almost daily maintenance dredging of the inner harbour is required in some ports. Permits issued for dredging-related dumping by harbours along the GBR coast allow for up to 94,000 tonnes annually by small ports such as Mackay, to 450,000 tonnes in larger ports such as Townsville. Impact of these operations varies according to amount and type of sediment being moved, whether sediment is contaminated, weather conditions during dredging, and proximity of sensitive environmental areas.

Extensive monitoring programs are underway in both Cairns and Townsville to determine impacts of port dredging and dumping on sensitive areas of the Marine Park. To date, however, nutrient regeneration from resuspended sediments has not been investigated.

Whereas the quantity of material excavated and disposed of in marine construction on islands and the coast is quite small compared to an operational port, the resulting silt and resuspended nutrients are frequently in close juxtaposition to fringing reefs, which are highly sensitive to additional silt and nutrients. Resuspension of sediments has been reported to occur for several weeks at disturbed sites in the GBR (Fisk, pers. comm; Hocking, pers. comm.) with obvious effects on biota (van Woesik, 1990). Gabrie (1985) reports that even though there has been no excavation at a site in Fa'aa, French Polynesia for seven years, visibility is still less than 1 metre. He claims that the fine particles are resuspended at the first movement of the sea.

Monitoring programs are required at all marinas being constructed in the Marine Park. There are a variety of techniques available to minimize impact from dredging, including limiting areas to be dredged, silt curtains, restoration of damaged sites, construction of marshes or spoil islands, inland disposal, diked disposal sites, and alternative engineering solutions which avoid excavation (Morton, 1977; Gabrie et al 1985). The permit issued after impact assessment for a marina construction on Magnetic Island, required silt curtains to be used during excavation and diversion of silty water away from the fringing reef.

Results of studies over the Middle Atlantic Bight continental shelf, indicate that sediment resuspension by trawling can be a primary source of suspended sediment over the outer shelf, where storm-related bottom stresses are usually weak (Churchill, 1989). The concentration estimates further suggest that sediment resuspended by trawls makes a sizeable contribution to the total suspended sediment load over a heavily trawled central shelf area during all times except winter and spring.

The process of trawling for prawns and other commercial benthic species involves disturbance of the bottom sediments inshore, in the GBR Lagoon, and in inter-reefal areas. The extent of the creation of a disturbed layer has not been investigated, however it is expected that bottom sediments may take several weeks to settle and would be affected by any other major disturbances such as storms (E. Wolanski, pers. comm.).

Following Cyclone Winifred which crossed the central GBR early in 1986, Furnas (1988) found that concentrations of inorganic nitrogen, ammonium and nitrate, were greater than 1 μM in the inter-reef and lagoon waters. Following the injection of large amounts of nutrients into shelf waters, a pronounced phytoplankton bloom developed in the cyclone path within 2 days. Chlorophyll concentrations were frequently 5 to 10 times higher than normally measured in mid-shelf waters. Preliminary nutrient budgets for the event indicated that most of the phosphate and silicate added to the water column could be accounted for by inputs from rainfall, river runoff and porewaters in disturbed shelf sediments. In contrast, existing nitrogen stocks plus inputs from the above sources accounted for less than 25% of the nitrogen present in the post-cyclone water column. Partial mineralisation of organic nitrogen in the column of shelf sediments resuspended by Winifred can easily account for the discrepancy (Furnas, 1988).

This activity was confirmed by Gagan and Chivas (1988) whose sediment analysis suggested that sediment derived from near-record flooding of the Johnstone River did not move more than 15 km; reef detritus was swept up to 1.5 km shoreward to the mid-shelf; and resuspended mid-shelf sediment was driven at least 15 km shoreward to the inner shelf.

SUMMARY: Section One

Nutrients can have an effect on the entire reef ecosystem from mangroves and seagrasses to coral reef communities. Evidence of disturbance from enhanced nutrients is usually seen by an increase in filter-feeders and algae and negative effects on abundance, diversity, and growth rate of corals.

From review of some case studies, it is seen that most of the negative effects from nutrients resulted from at least one of the following factors:

1. a high volume of nitrogen and/or phosphorus discharged;

2. poor circulation and dispersion in the receiving waters;

3. a site subjected to long-term chronic discharge, then possibly exposed to an acute event such as a storm or short-term excavation, leading to extremely slow recovery of the system.

The levels of nitrogen and phosphorus in Barrier Reef waters, especially in the central GBR are close to those levels which have caused concern elsewhere, and are much higher than in the more pristine northern Reef waters.

Though evidence of damage to coral communities from nutrients is still primarily circumstantial, recent monitoring of sites in the GBR has illustrated a cause for concern. Examples include: localised impacts at locations such as Hayman and Green Islands; perturbations in water quality and benthic communities in the Cairns Section of the Marine Park generally; and a possible relationship between some aspects of terrestrial run-off and Crown-of-Thorns Starfish.

Sources of nutrient input into the Marine Park are many and range greatly in volume and timing. Point source discharges into the Marine Park either directly or indirectly are relatively easily identifiable, quantifiable, and amendable. Depending on environmental sensitivity of the place of discharge, they may have serious but relatively localised effects. The scale of impact is related to volume and content of discharge, continual discharge conditions, and circulation characteristics of receiving waters.

Discharges from "minor" sources such as boating and shipping are seen as less of a concern in terms of quantity and potential for location of discharge away from sensitive sites. Impacts from these sources are difficult to quantify. If discharge is not handled sensibly, such sources may affect mid and outer shelf reefs which are not normally subjected to elevated nutrient levels.

Terrestrial runoff is a major source of nutrient input to Reef waters. It is estimated to supply 8 to 10 times the nutrient load as point source discharges. It is more difficult to quantify and more complex a situation to remedy. The pulse effect of this type of discharge may be beneficial to some organisms to the detriment of others. As the central section of the GBR is more subjected to heavy runoff, due to higher rainfall, more intensive adjacent land use, and the reef being close to the coast, it is this area that needs the most input in terms of management action.

SECTION TWO

MANAGEMENT IMPLICATIONS

INTRODUCTION

Nutrient levels in inshore GBR waters are close to or at levels that have caused detrimental effects to coastal and reef communities elsewhere. Evidence of stress on the reef system is becoming apparent in some areas of the GBR. As a result, a conservative long term management strategy should ensure that levels of nutrients in the GBR Region not be allowed to increase in the future through human use. In fact, where existing levels near coral reefs are shown to be higher than those compatible with reef health, attempts should be made to reduce the levels over the long term.

In this section, GBRMPA's and the Commonwealth government's responsibility for management action is delineated. Relevant legislation is presented but the following in no way represents an evaluation of the current legislation. The opportunity to proceed towards remedial action in conjunction with the Queensland government is highlighted. Specific management action is recommended, including further research and monitoring.

LEGISLATION

The object of the Great Barrier Reef Marine Park Act 1975 is "to make provision for and in relation to the establishment, control, care and development of a marine park in the Great Barrier Reef Region" (S 5(1)). The prime means of management of the Marine Park is through Zoning Plans. In preparation of a plan, Section 7 of the Act requires that regard shall be had to the following inter alia:

"(a) the conservation of the Great Barrier Reef

(b) the regulation of the use of the Marine Park so as to protect the Great Barrier Reef while allowing reasonable use of the Great Barrier Reef Region;"

The Act provides for the regulation or prohibition of "acts (whether in the Marine Park or elsewhere) which may pollute water in a manner harmful to plants or animals in the Marine Park" (S.66 2(e)).

Discharges Outside the Marine Park

The provision that sources of pollution "in the Marine Park or elsewhere" may need to be considered, is of particular significance as it is one of the few provisions of the Act relating to the management of activities which are not entirely within the boundaries of the Marine Park. Recent legal advice has confirmed that regulations could be made under S.66(2)(e) of the Act to regulate indirect discharge of waste into the Marine Park. Amendments to the legislation would be required. In normal circumstances the Authority would not seek to use this regulatory mechanism but instead would prefer to collaborate with other relevant agencies to achieve a common goal of protection of the environment through application of appropriate discharge standards.

Discharges Within the Marine Park

A permit is required for waste discharge into the Marine Park. The Regulations, drafted in accordance with the Act, specify that the written permission of the Authority is required prior to discharging or depositing "household, industrial or commercial waste in the Marine Park", with the following exceptions:

a) where a Zoning Plan provides for the Zone to be used or entered for that purpose;

b) the discharge of human waste from a vessel or aircraft which does not contain a storage tank of a kind designed for the storage of human waste;

c) offal from fish caught in the Marine Park;

d) other biodegradable waste from a vessel or aircraft which is more than 500 metres seaward from the seaward edge of a reef. (GBRMP Act, Section 38)

Some resorts do not require GBRMP permits because they dispose on land by irrigation or conventional sullage trench (7 in total). A number of resorts (approx.7) have secondary treatment of sewage and discharge the treated effluent in the Marine Park; at least 5 other resorts are in the process of upgrading their treatment systems.

Conditions attached to most recent GRBMP permits for waste discharge specify the flow rate of effluent and quality of effluent to be 20 mg/l Biological Oxygen Demand (BOD) and 30 mg/l Non-filtrable Residue (NFR) based on Queensland discharge standards. Effluent quality and volume are to be monitored. Records are to be maintained and presented on application for a permit renewal. Outfalls are required to be at depth beyond the reef edge. In some cases, where discharge is occurring near the reef edge, the permittee is required to monitor receiving waters for nutrients, temperature, and salinity.

The Queensland Clean Waters Act 1971-1988 seeks to regulate discharges which are likely to cause damage to the environment of the territorial waters of the State of Queensland. This includes discharges from island resorts where the islands are not Commonwealth owned (i.e. most of them). Conditions on these licences have provided the basis for Marine Parks permits.

As coastal urban centres such as Townsville and Cairns discharge indirectly into the Marine Park via mainland rivers, they do not require a permit from GBRMPA. Regulation is through the State legislation.

As mentioned previously, regulation of vessel-based sewage discharge and biodegradable waste is administered through GBRMP Act Section 38. At present, discharge of human waste from a vessel is allowed anywhere if there is no holding tank. If a holding tank is on board, human waste may be discharged more than 500 m beyond the reef edge. Discharge of biodegradable waste is allowed more than 500 m seawards of the reef edge.

Australia is party to the MARPOL Convention (controlling international marine pollution) which inter alia prohibits discharges of offending substances within the Great Barrier Reef Region. Regulations to the Commonwealth Protection of the Sea Legislation Amendment Act 1986 legislation will give force to Annex IV and V of this International Convention for the Prevention of Pollution from Ships.

Annex IV proposes that ships of 200 tons gross tonnage and ships which are certified to carry more than 10 persons must have holding tanks for sewage wastes and must discharge wastes only outside of the Great Barrier Reef Region, for example, at an appropriate waste receiving facility in a port or several kilometres from the outer edge of the continental shelf. This portion of the Act will only take effect once the Annex has been ratified by 50% of nations representing 50% of the world shipping tonnage; expected to take several more years.

The recent entry into force internationally of Annex V relating to garbage,and Australia's intention to become party to that Annex means that discharge at sea from ships will be prohibited:

- everywhere, for all plastics including garbage bags
- within 25 nautical miles of the outer edge of the GBR, for dunnage, and packing material that floats
- within 12 nm of the outer edge of the GBR, for biodegradable waste, rags, paper, and metal; or within 3 nm of the outer edge of GBR for biodegradable waste if put through a comminuter or grinder (Regulation 3, International Maritime Organisation, 1988).

In this regard, a "ship" means any vessel of any type whatsoever operating in the marine environment and includes hydrofoil boats, air-cushion vehicles, submersibles, floating craft and fixed or floating platforms (International Maritime Organisation,1988). The implications for small vessels in Barrier Reef waters may be unworkable. The Authority is looking at this matter carefully.

The implementation of the MARPOL Convention may have significant implications for ports, marinas, and urban sewage treatment and solid waste disposal facilities adjacent to the Great Barrier Reef due to an increasing demand for waste disposal services.

The Commonwealth Environment Protection (Sea Dumping) Act,1981 regulates, amongst other things, the dumping of wastes and other matter from vessels, aircraft and structures into Australian waters. For the purposes of this Act dumping does not include discharge of human waste from a vessel, aircraft or structure where that activity is incidental to normal operations. Where an application for a Sea Dumping Permit to discharge in the Marine Park, or potentially affecting the Marine Park, is made to the Department of the Arts, Sport, the Environment, Tourism and Territories, comments are sought from a number of agencies including GBRMPA. GBRMPA has been consulted in the case of six Sea Dumping permits to date; dumping of treated effluent from the John Brewer Reef Floating Hotel outside of John Brewer Reef; dumping of dredge spoil in the operation of Cairns, Townsville, Bundaberg and Mackay Port Authorities; and dumping of kitchen waste from Heron Island Resort.

Action is proceeding to delegate to the Chairman of the Authority powers under the Environment Protection (Sea Dumping) Act in relation to dumping in the GBR Marine Park.

COOPERATION BETWEEN GBRMPA AND QUEENSLAND GOVERNMENT AGENCIES

The most immediate action that can be taken by GBRMPA in relation to reef water quality under its legislation is to develop consistent guidelines for direct discharge into the Marine Park from point sources. This will assist in maintaining quality of reefs on a localised scale.

As Queensland Department of Environment and Heritage (Q.DEH) has responsibility for maintaining water quality and licensing discharge in State waters, cooperative action between GBRMPA and Q.DEH is essential for effectively protecting water quality.

At present there is consultation between GBRMPA and Q.DEH on all permit and licence issuance for waste discharges into the Marine Park, with the objective of applying complementary standards. Data required by licence and permit conditions are shared by the two agencies. Relevant data acquired by Q.DEH in the course of regular monitoring along the coast are also shared with GBRMPA. GBRMPA's data are likewise shared with Queensland agencies.

To date Queensland standards for waste discharge have been applied by GBRMPA at island resorts. With the concern that coral reef biota are susceptible to enhanced nutrients, the Marine Park Authority has realised a need to develop guidelines for waste discharge in consultation with Q.DEH, initially regarding permit conditions for point source sewage discharge directly into the Marine Park (this paper).

In addition, an increasing number of developers are being required to monitor the impact of their developments on the biota in the Marine Park. This includes monitoring water quality for nutrients and suspended sediments. Advice on design of water quality monitoring programs from Q.DEH is incorporated into such projects.

GBRMPA has established a Water Quality Advisory Committee to determine priorities for integrated water quality monitoring. A representative of Q.DEH is a member.

A number of research projects have benefited from the cooperation of Queensland Water Resources Commission, Queensland Department of Primary Industries, and Queensland Department of Environment and Heritage. The Authority has initiated a three year study to determine ambient levels of nutrients and suspended sediments across the shelf between Cairns and Townsville. Once completed, this will give a better idea of the normal range in variability of the system. Studies are also being undertaken at sites which were identified as priority areas at the Workshop on Nutrients in the GBR (Baldwin, 1988). In addition, the Crown of Thorns Starfish research program has funded research into use of agricultural chemicals at specific locations along the coast and effect of mainland discharges on corals.

Thus, advantages of close co-operation and involvement between GBRMPA and Queensland government agencies are:

- integration of marine and terrestrial components
- cost effectiveness of long term monitoring,
- on-land management facilitated , minimising need for excessive and costly waste treatment
- sharing advice on treatment system, dilution and dispersion studies
- complementary permit/licence system for ease of applicants for permission to discharge waste
- coordinated educational program.

RECOMMENDED MANAGEMENT ACTION

1. GBRMPA to devise in consultation with Queensland government agencies, guidelines for point source discharge into the Marine Park.

2. GBRMPA to discuss with Queensland government agencies appropriate standards for point source discharges indirectly into the Marine Park, for example for urban centres adjacent to the coast.

3. GBRMPA staff to review GBRMP regulations regarding discharge of waste from a vessel to determine the need for recommending holding tanks on vessels of a certain size. GBRMPA staff to also review implications of the MARPOL Convention for vessels of Barrier Reef waters. An information program should be implemented to advertise the

need for and details of these management tools, targeting boat owners and builders, and port and marina operators.

4. GBRMPA to discuss with Queensland government agencies, the need for limiting the supply of nutrients in terrestrial runoff adjacent to the Marine Park, particularly in terms of erosion control, level and timing of fertiliser use.

5. Information should be provided to Local Authorities and Ports concerning nutrient effects on the Reef and implications of GBRMPA and other Commonwealth legislation in terms of sewage discharge, coastal developments, and marina construction. In particular, ports and marinas should be encouraged to plan for adequate waste pump out and treatment facilities in the near future.

6. Monitoring programs should be continued at all marine excavations in the Marine Park and policy should be developed regarding excavations at the limited fringing reefs with alternative options to be encouraged.

7. An extensive research and monitoring program should be adopted to monitor trends in water quality and effects on biota in the GBR and to research many of the unknowns related to water quality issues such as Crown-of-Thorns Starfish and trawling.

RESEARCH AND MONITORING REQUIREMENTS

1. Variation over time of ambient levels of nitrogen and phosphorus across the shelf in the GBR Region needs to be determined. To date, most measurements have been fairly localised or preliminary in nature. In 1988-89, GBRMPA began funding a long term study by Australian Institute of Marine Science (AIMS) to construct a nutrient budget in the central GBR region. A preliminary study in the Shelburne Bay transect area will be commenced in 1989-90 by AIMS. Initial results of these two studies will be used to determine the extent of future work.

2. Once present levels of nutrients are measured reliably, a comparison needs to be made with historical data. There are limited historical records available on nutrients in the GBR, primarily because technology has only recently advanced to the point where nutrients can be measured accurately at the comparatively low levels found in marine waters. One method which is currently being explored is tracing phosphorus levels in coral skeletons. This area is still under development and is being funded to a large extent by GBRMPA's Crown of Thorns Starfish Research Program. There is currently no method of determining historical nitrogen levels.

3. Measurements of nutrient levels in river input into the GBR need to be made, particularly during peak flow conditions, for input into a nutrient budget for GBR waters. Estimates of phosphorus levels in rivers adjacent to the Cairns Section have been provided by Cosser (1988a). Average levels are being collected by various researchers along the north Queensland coast, however, peak events are often missed and logistically difficult to access. Involvement of Queensland government agencies is essential for the development of coordinated studies in this area.

4. Levels of nutrients originating from resorts are based on typical discharge values. Nutrient levels of permitted discharges need to be measured to determine if they vary from the typical. The characteristics of resort waste may vary according to visitor numbers,season, time of day and purposes of water use. Data on nutrient levels in effluent should be required as a permit condition for all resorts, at least for a year.

5. Tolerance levels of different species of corals and other reef biota to varying levels of and exposure time to, nitrogen and phosphorus need to be determined if possible. The symptoms associated with stress levels need to be recorded. The possibility of undertaking preliminary studies in conjunction with the GBR Aquarium is being investigated.

6. The effectiveness of reducing phosphorus at resort discharges by use of phosphorus-free detergents, needs to be evaluated. Costs and sources of phosphorus-free detergents are being sought. A comparative study involving use of P-free detergents at interested resorts should be investigated.

7. Levels of nutrients resuspended by dredging or trawling activities should be quantified to determine whether these activities provide a substantial input to the nutrient budget of the Reef.

SUMMARY: Section Two

GBRMPA has a clear mandate to regulate point source discharges into the Marine Park. These have potential to have serious but localised impact on coral communities. It is essential that guidelines for direct waste discharge be developed immediately. The expertise, advice, and cooperation of relevant Queensland government agencies will be sought in this process.

Management of some of the "minor" inputs of nutrients by vessels is taken care of through the GBRMP Act and future adoption by the Commonwealth, of Regulations putting into force the MARPOL Convention. GBRMPA staff need to review all such regulations to ensure the most appropriate, effective, and enforceable regulations are adopted. A directed education program then needs to be instituted.

Monitoring programs related to dredging and dumping in the Marine Park should be continued or instituted, depending on the case. Research and monitoring should be initiated or continued on ambient levels of nutrients in the GBR, nutrient effects on reef biota through manipulative studies and in the field at potential impacts sites, in areas where there is still limited knowledge such as remobilisation of nutrients by resuspended sediment.

SECTION THREE

GUIDELINES FOR POINT SOURCE DISCHARGE INTO THE MARINE PARK

INTRODUCTION

A number of important sources of nutrient discharge into the Marine Park are known. These include sources originating both within and outside the Marine Park. An approach to regulating those sources outside of the Marine Park need to be developed by industry itself or by Queensland government agencies. The Authority will work with those agencies where it can make a contribution.

As discussed in the previous section, sources of discharge within the Marine Park can be controlled by a variety of mechanisms available to the Authority, including education, specific permit conditions, regulations and reliance upon international conventions such as MARPOL. This section focuses on guidelines for waste discharge permits, as a prime mechanism for control of waste discharge into the Marine Park.

To date, assessment of new permits for waste discharges into the Marine Park has been undertaken in consultation with QDEH. Existing permits for the discharge of sewage into the Marine Park have utilised standards applied by QDEH. These standards address the location of outfall pipes, diffusion rates, non-filtrable residue (NFR) levels, biological oxygen demand (BOD) and disposal of sludge.

Although in some instances increasing BOD levels can be correlated within increasing stress symptoms on coral reef communities (Tomascik et al, 1985), often there is no relationship. For example, studies in Kanoehe Bay showed that sewage discharge had not markedly affected dissolved oxygen or BOD outside the immediate areas of discharge, yet there was significant coral mortality away from the outfall (Banner, 1974). In addition, it has been suggested in one study that BOD measurements do not adequately assess the environmental impact of sewage effluent because of important limitations on the BOD test. These are: it does not indicate the presence of organics which are not degraded under the prescribed conditions; it assumes that no toxic or inhibitory materials will affect microbial activity; and it does not measure the nitrogenous oxygen demand of the organic waste (Water Quality Criteria, 1972; Bell et al, 1987b).

Guidelines need to be adopted by GBRMPA that take into account concerns for nutrient effects on reef biota. These guidelines need to provide clear direction for those applying for waste discharge permits and for those assessing such applications.

Point source discharges into the Marine Park are primarily from:

. resorts or research stations on high islands or cays,
. coastal discharges from small communities, marinas or resorts,
. fixed structures such as floating hotels and pontoons.

The latter, due to usually being located on the lee of reefs having poor circulation characteristics and in locations not adapted to high nutrient loads , should not be permitted to discharge into surrounding waters. In event of any permit applications for discharge from fixed structures, reference should be made to management and monitoring criteria applied to John Brewer Reef Floating Hotel. This type of discharge will not be discussed in greater detail in this paper.

FACTORS TO CONSIDER IN DEVELOPMENT OF GUIDELINES

The objective of these guidelines is to minimise effects of nutrients from point source discharge on reef biota through maintaining or improving quality of receiving waters.

For waste discharge to minimise environmental impact, the options are:

- prevent specific components entering sewage stream
- removal of components from waste by treatment
- dilution prior to or at point of discharge

PREVENTION

1. Use of phosphorus free detergents to reduce the phosphorus content of an effluent discharge.

2. Treated water may be reused for irrigation of gardens rather than discharged to the ocean. It is commonly practised and Queensland Department of Environment and Heritage, Division of Environment has guidelines for use of treated water for irrigation, to safeguard public health. However,as high nutrient concentrations in run-off water may cause problems for reef corals, run-off in the vicinity of a reef would need to be controlled, diverted, and possibly treated to minimise impact. Nutrient loading from such run-off should be determined.

3. All future developments should be designed to minimise the impact of run-off on the reefs. Developments should be located away from the reefs. Other factors to be considered are:

- the minimisation of disturbances to the existing landscape
- the use of Australian native shrubs and trees in preference to exotic plants and lawns - such native plants normally require little or no fertilizer; lawns increase run-off and require fertilizer
- the use of contouring to divert run-off to storage areas. The storage areas could be either of a permanent type (eg. dams) or a temporary nature eg. large low lying land areas from which evaporation would be enhanced. Storage areas would only be appropriate if they reduced nutrients reaching the marine environment.

SEWAGE TREATMENT

There are three levels of sewage treatment generally recognised. The resulting effect on N & P levels is sumarised in Table 8.

Primary treatment/Septic

The removal of solid matter, through a sedimentation tank reducing and settling out microbial biomass and flocculated organic matter. Septic tanks are considered equivalent to "primary" treatment with no significant breakdown of carbon, nitrogen, or phosphorus. Septic tanks have been used at smaller resorts with varying degrees of success. In their simplest form septic tanks are pits in which settleable solids are held for a length of time sufficient for anaerobic digestion to occur. Effluent is then absorbed from the pits into the surrounding substrate, drained into an adjoining absorption field, or pumped out into the ocean. Though septic systems are simple and inexpensive, they are susceptible to certain problems. A layer of sludge accumulates and must be removed every few years. As pumping out a septic tank is logistically complicated on islands or in isolated areas, it is frequently overlooked. Problems of rising sludge can cause incomplete digestion and odours. Septic systems tend to become saturated after a few years with a subsequent decrease in efficiency and possible groundwater contamination.

Septic systems are not recommended at any resorts due to potential odours, possible groundwater contamination and lack of treatment for nutrients.

Secondary treatment

The breakdown of most organic waste to more simple compounds by oxidation, through bacterial or chemical action, such as activated sludge. The activated sludge process involves pumping of settled sewage into aeration tanks, oxidation, then sedimentation. The excess activated sludge is anaerobically degraded in digestion tanks (Higgins and Burns, 1975).

Secondary treatment involving biological breakdown of waste, does not significantly reduce the nutrient concentration of the effluent stream, but reduces suspended sediments (SS) and biochemical oxygen demand, (BOD, a measure of biodegradable organics).

For example, phosphorus reduction in conventional secondary biological treatment processes was found to be limited in the Gold Coast region, where there was an average total phosphorus concentration of approximately 6.8 mg/l in raw sewage compared to 5.6 mg/l in treated effluent (Camp et al, 1976). The latter is considered typical for conventional activated sludge process effluents.

Tertiary Treatment

A further stage of processing may include near elimination of bacteria by chlorination or ultraviolet radiation, filtration, and/or the removal of nutrients to some degree.

Chlorination is the most generally accepted method for effluent disinfection for protection of public health, through reduction of coliform bacteria, an indicator of possible faecal contamination. Chlorination has been found to have little effect on some pathogens such as enteroviruses and parasitic worms. Modifications of chlorine application practices may be needed to protect marine biota if residual chlorine or organic chlorine effects are shown to persist in the receiving waters. One possible method of chlorine residual elimination is by dechlorination processes prior to effluent discharge. This usually involves either use of sulphur dioxide or activated carbon (Camp et al, 1976).

An alternative method of removing almost all human bacteria and viruses is by means of multicell stabilisation ponds with a 20 day day retention time. These are low cost, relatively easy to operate and can produce an effluent suitable for irrigation of even vegetables (Falkenmark, 1987). Possible use of this system on islands is limited due to space requirements.

Two systems are commonly in use as a means of polishing the effluent after secondary treatment. They are capable of achieving an effluent quality of 5 mg/l BOD and 5 mg/l suspended solids. They are however somewhat limited in their effectiveness at removing nutrients. Filtration removes suspended matter from water by passage through a porous substance, usually sand.

Activated carbon removes organic contaminants from water by adsorption and is especially effective at removing dissolved organic compounds including many which are non-biodegradable.

Nutrient Removal: Control of Nitrogen and Phosphorus in Effluent Discharge

An advantage to removing nutrients is that it can reduce turbidity to low levels which can be important for recreational/tourist areas.

Removal of nitrogen can be accomplished by chemical or biological means. The chemical methods used are breakpoint chlorination, ammonia stripping, and ion exchange while biological N removal involves nitrification/denitrification. The latter system is expected to achieve greater overall N removal and is the system most commonly used. (Australian Environment Council, 1987). Nitrogen concentration in effluents from correctly designed and operated plants would generally lie in the following ranges:

organic N 1-3 mg/l
ammonia N 0.5-1.5 mg/l
nitrate N 2-7 mg/l.

Phosphorus may be removed from wastewater by chemical, biological or combined chemical/biological means. Chemical P removal is generally achieved through precipitation of P using the mineral salts (aluminium sulphate, ferrous and ferric chloride and sulphate, and sodium aluminate) and/or lime. Iron-based chemicals are not recommended due to significant carryover into effluent resulting in discoloration and possible effect on biota.

Biological P removal involves a process modification to the activated sludge process such that organisms that are able to take up P far in excess of their normal growth requirements are encouraged to proliferate within the activated sludge. It is relatively new technology.

The chemical process for P removal is more commonly used and produces a more consistent effluent quality, achieving P reduction of up to 95% or P levels of 1-2 mg/l and possibly as low as 0.1-0.2 mg/l.

The disadvantages of chemical P removal are listed as:

- high level of personnel expertise
- recurring chemical costs
- increase in effluent salinity (should not be a great problem for marine waters)
- alkalinity reduction
- increased sludge production, although this can vary greatly. (AEC, 1987)
- care in use of mineral salts to minimise effects on reef biota.

Biological treatment to remove nitrogen from effluent (dentrification) and chemical treatment to remove phosphorus are, at present, the best methods to use at small scale treatment plants typical at resorts. Capital costs are estimated at approximately 20% higher than secondary treatment (D Barnes, pers. comm.). However, nutrient removal requires specialised maintenance, incurring extra costs for trained personnel and operating expenses (chemical additives).

Phosphorus input can also be controlled at source. Approximately one half the phosphorus in sewage results from the use of detergents and shampoos (Bell et al, 1989). If adopted discharge standards required low levels of P, considerable cost savings in the disposal of sewage effluent would be achieved if this source were reduced by substituion with phosphorus-free detergents. If secondary treatment only was required, controlling phosphorus input at source would still be advantageous to receiving waters.

Sludge Treatment

A major by-product of any level of sewage treatment is a sludge fraction. Collected sludge is less than 1% of effluent volume but contains very high concentrations of nutrients (Bell et al, 1987). Some plants have the ability to treat sludge by digestion to reduce organic material.

Wet sludges are often partially dewatered in order to reduce the bulk of the solids producing more easily and economically handled material for final disposal. The various methods used to dewater sludge in approximate order of simplicity and economy are: sludge lagooning, drained drying beds, vacuum filter dewatering, filter pressing centrifugal dewatering, and one of the aforementioned followed by incineration (Camp et al, 1976). Each of these have their own advantages and would need to be evaluated in terms of space available, likelihood of odour problems and air emissions, and logistics of removal.

EFFLUENT DISPOSAL

Land Disposal of Treated Effluent

Land disposal of treated effluent may be an economically attractive means of water conservation while reducing the nutrient load to some degree. Many of the tourist islands experience some difficulty in obtaining adequate quantities of good quality water. Land disposal of effluent may assist in irrigation of landscaped areas in some cases. The potential for land disposal of treated effluent by irrigation is under-utilized at almost all resorts. The following resorts are presently using effluent for irrigation to at least some extent:

Hayman Island
Contiki Whitsunday (Long Island)
Brampton Island
Dunk Island.
Lady Elliott Island

The following resorts have potential for disposing of a significant proportion of treated effluent via irrigation:

Lindeman Island (could use 100%)
South Molle Island
Hamilton Island
Hinchinbrook Island.

Other existing resort islands are constrained in some manner, such as lack of available area or unsuitable terrain (eg Bedarra and Green Islands).

Small scale re-use of effluent for garden verges, etc. using reticulated sprinklers, micro-sprays, or similar systems, would require an additional filtration system to be added to prevent clogging of sprinkler orifices. Such a system is to be used at Hayman Island to allow increased effluent use (Qld. Dept. of Conservation and Heritage, 1989b).

Techniques and processes (such as sand filters, chlorination and stabilisation ponds) are available to treat waste water to standards which would allow its use for non-domestic purposes such as garden and lawn watering. Advisability of use of treated effluent for irrigation needs to be carefully considered in areas of high rainfall, where the evapotranspiration rate would need to be taken into account. Though irrigation may reduce nutrients in the effluent to some extent the comparative amount and form of nutrients entering via surface run-off and the groundwater system to the marine water column needs to be evaluated.

Run-off is not easily controlled, especially after a tourist development is complete. Strategies to minimise the impact of run-off should be considered in design and construction of resorts.

Ocean Outfall Disposal of Treated Effluent

At some resorts, sewage is treated to some degree and the effluent disposed of via submarine outfalls. The objective of an ocean outfall is to design it to use the natural processes of the receiving water to dilute and disperse wastes so that the discharge is assimilated by the marine ecosystem without significant adverse environmental effects. Dilution is only an option where ambient water quality is compatible with system health.

Outfalls should be designed to encourage maximum mixing with receiving waters and to achieve the greatest dilution possible at the nearest reef. Sewage discharges usually are lighter than seawater. The deeper the outfall the greater potential for mixing. The outfall pipe should be located far from the nearest reef ensuring that diluted effluent does not flow onto the reef under varying tidal and wind regimes. This can be achieved through sufficient length of outfall pipe, discharged as deep as is feasible, most likely perpendicular to the prevailing current, and incorporation of a diffuser in the pipe design to distribute the flow and ensure maximum mixing.

Theoretically high dilutions of the required orders (10^3 - 10^5) could be achieved with correct diffuser design if suitable locations for discharge were available, according to Bell et al (1989). Typically, diffusers of lengths 10 - 100 m set at depth of 10 m or more may be required to achieve adequate initial dilution. Long diffusor lengths may require the use of additional pumping energy to distribute the discharge stream uniformly along the diffuser.

Tolerance Levels

Although this paper emphasises the effects of nutrients in direct waste discharges, in actuality, there may be other wastes which are also a potential concern such as chlorine and surfactants. With the current rate of development at resort islands, the need for increased 'fresh water' supplies is expanding which in turn is increasing the production of hypersaline effluents from desalination plants. Use of some chemicals associated with the desalination process, such as flocculants, may have associated risks, however it is expected that if discharge of all waste is through outfalls designed to maximise dilution, the risks of pollution would be minimal.

The relative sensitivity of water quality parameters as indicators of eutrophication in the Kaneohe Bay Study were found to be, from most sensitive to least: Chlorophyll a, inorganic phosphorus, particulate nitrogen, adenosine triphosphate, with secchi disc, particulate inorganic and organic carbon, ammonium, inorganic nitrogen, nitrate and nitrite being relatively insensitive (Laws and Redalje, 1979).

Based on studies reviewed, it is likely that nutrient levels (total phosphorus and total nitrogen) elevated to two or three times the normal ambient levels can cause increased primary production and biomass in both phytoplankton and benthic algal populations, affecting coral nutrition, growth and survival (Bell et al, 1987b).

Tolerance levels are usually arrived at on the basis of estimates from extrapolation of lethal levels; estimates from field observations; and estimates from the absence of sublethal or chronic effects in laboratory tests. Bell et al (1987b) estimate tolerance levels for coral reefs based on sublethal limits determined by direct observation or extrapolation of results from reef studies or in their absence, application factors recommended by the USEPA for marine waters, based on reef organism LC 50's where possible. Table 9 provides an estimation of their proposed tolerance levels for coral reefs to a number of water quality parameters. It must be noted that there is a need for verification of these estimates.

Though this provides a starting point for discussion, it is generally acknowledged that a widely applicable tolerance level of corals to water quality parameters is difficult to establish. Ambient water quality levels vary according to reef and position on reef, with individual coral assemblages adapted to their surrounding waters. In addition, different species of corals appear to be more tolerant to variations in water quality than others.

As the levels of nutrients in tropical waters are very low, they are difficult to accurately and consistently measure. In the interest of keeping the Tables in this report clear in terms of the message presented, standard deviations have not been presented. By referring to the original studies one can see that standard deviations for such measurements are frequently as high as .50. Care must also be taken to standardise weather conditions during sampling if possible. Turbulence and mean residence times of waters have a strong influence on the uptake of nutrients and the type of algae that will grow.

Bell et al (1987b) proposed that water quality standards be determined in relation to background levels and a 10% increase over background levels. So in reference to Table 9, measuring 2 times the ambient levels of nutrient may be difficult to achieve, let alone a 10% increase. A huge number of samples would be required to achieve statistical validation.

Required Dilution Factors

The required dilution factors for a number of the components of primary, secondary and tertiary treated domestic sewage to meet criteria recommended by Bell are given in Table 9. The levels of dilution required for phosphorus and nitrogen are particularly high. It is clear that if the dilution criteria for the nutrients are met then the criteria for all other components, both major and minor, should easily be met. However, it is stressed here that even the proposed required initial dilution factor for tertiary treated sewage is an order of magnitude greater than is normally achieved with conventional marine outfall systems.

Sewage Sludge Disposal

Due to the fact that sewage sludge tends to concentrate many harmful constituents (eg. heavy metals, toxic organics, nutrients), discharge of sludge to the marine environment should never be considered as a disposal option. Land disposal of sludge on some island resorts is currently practised. Spreading the digested sludge over dry land is an acceptable method of disposal on the mainland given certain conditions. However, there may be a lack of suitable land on many resort islands. This option needs to be looked at carefully as there is potential for sludge to be a significant source of pollution of the groundwater, surface water and ultimately marine water.

Nutrient removal results in sludge that is denser than secondary sludge but is not much greater in volume (D Barnes, pers. comm). Consequently, disposal of sludge should not be an increased problem as a result of nutrient removal. Removal of sludge to the mainland is preferable.

NUTRIENT REMOVAL REQUIREMENTS ELSEWHERE

The following three examples of government adoption of nutrient removal standards are of interest. The Australian example of Kosciusko National Park illustrates feasibility of adoption of such processes in conditions similar to many GBR resorts but also the difficulties of technically achieving the desired results. The example of Cyprus is logistically similar in many ways to Barrier Reef resort islands, but is all the more impressive in that tertiary treatment costs are being accepted by tourist complexes in an undeveloped country in order to maintain environmental quality. The third example that of Sweden, is provided as an example of where tertiary treatment processes have been widely in use in urban areas for ten years but are not seen to be achieving the objectives.

Kosciusko National Park

Nutrient removal is a standard condition of discharge in Kosciusko National Park, New South Wales. Other than the colder climate making nutrient removal technically more difficult to control, conditions are similar to those applying to many GBR resorts: remoteness, cost of transport, personnel previously untrained in sewage treatment, peak use periods resulting in fluctuating flow volumes (J Davis, pers.comm.).

The draft Kosciusko stream quality report based on surveys conducted during 1980 and 1981, found that most impact on the streams was caused by sewage discharges rather than diffuse pollution from the villages. It also found that the stream water quality below the sewage outfalls was poor, especially with respect to nutrients (total nitrogen, ammonia, and phosphorus), and faecal coliforms, and that such discharges were not consistent with the desired water quality objectives.

At that time most of the sewage treatment works in the area provided secondary treatment with little or no disinfection and no nutrient removal, while some relied on disposal by septic tanks and absorption trenches. Licences required a 20/30 effluent standard.

In 1984 existing sewage treatment facilities were reviewed in line with desired water quality and it was decided that new sewage treatment augmentations should be designed to meet the following effluent criteria and that existing treatment works should be upgraded within a reasonable time to comply with these standards:

20 mg/l BOD
30 mg/l NFR
10.0 mg/l NO_2 plus NO_3 (N)
1.0 mg/l total P
0.5 mg/l NH_3 (N)
not greater than 200 faecal coliform per 100 ml
6.5 - 8.5 pH

All sewage treatment plant augmentations have incorporated intermittent extended aeration treatment, use of an anoxic inlet zone to assist sludge formation and denitrification, chemical dosing for nitrogen and phosphorus removal, and ponding as well as ultraviolet disinfection of final effluent. Other safety features have been included such as standby pumps and back up diesel power and a full telemetering alarm system.

The status of treatment plants for this area which either have been, or are to be, upgraded is summarised in Table 10. The licence conditions for Perisher Valley Sewage Treatment Plant, for example, require, among other things, the monitoring of pH, BOD, NFR, ammonia, total P, nitrate plus nitrite determined on a representative sample on a monthly basis between July and September and three monthly between October and June. Data indicates that there are still problems at some of the recently augmented works but it is hoped that these will be rectified by the 1989 season (State Pollution Control Commission, 1988).

Cyprus

An overseas example of a tourist area attempting to modify its sewage treatment and waste discharge processes is in Cyprus. Cyprus is a popular tourist destination, with no permanent rivers and limited ground water resources. It has a Mediterranean climate: low average annual precipitation of 477 mm during the period 1951-1980; and high evaporation and evapotranspiration of 1800 mm and 1200 mm respectively. The supply of drinking water is mainly from water wells, so it is very important to protect underground water resources. Maintenance of sea water quality is essential to the viability of the tourist based economy.

Since 1979, approximately two hundred (200) small sewage treatment plants for hotels, restaurants, tourist complexes and communities have been installed mainly in coastal tourist areas of the island. The size of the sewage treatment plants is of the range of 50 to 1250 E.P. The disposal of domestic wastewater or even of the treated water into the sea is forbidden. Tertiary treatment standards are required for tourist complexes within 100 m of the sea. Tertiary processes usually include an equalisation tank, chlorination, addition of alum, and in some cases dechlorination by activated carbon filter (Larcou, 1987).

Sweden

In Sweden, chemical precipitation of phosphorus was rapidly adopted over a ten year period: in 1970 98% of the urban population had secondary or primary treatment of sewage; by 1980 almost 100% were served by tertiary treatment plants. The normal requirement was an effluent standard of less than 0.5 mg/l total phosphorus. The estimated load of total phosphorus from point-source discharges decreased from 50,000 kg annually in 1970 to 8600 kg by 1980. In general, the treatment process has been improving continually, leading to the use of lower doses of precipitation chemicals and to more reliable modes of operation (Lowgren et al 1987).

Though the system of sewage treatment had some important positive local hygienic and aesthetic effects, the study by Lowgren et al (1987) found that there was no sharp decline in the level of phosphorus transports in the Svarta River after upgrading systems and introduction of chemical precipitation.

The standards adopted have been criticised for the following. The objectives of the Swedish water pollution abatement program were not expressed in terms of improved water quality, but as the percentage of urban population served by a certain kind of wastewater treatment technology and effluent standards, despite the fact that recipient conditions varied greatly. Eutrophication was mainly a problem for the densely populated areas in southern Sweden. It was administratively and technically feasible to add another treatment step to many of the already existing systems. It did not specify removal of nitrogen which may be just as important as phosphorus in affecting eutrophication. It did not specify recipient conditions or give priority to removal of nutrients from severely polluted waters. The uniformity of the national effluent standards also hampered the development of wastewater re-use (Lowgren et al, 1987).

As a result of this Swedish study it is recommended that the most effective approach to formulating standards involves the following:

- to decide what water quality to aim for,
- to undertake a comprehensive nutrient budget specifying the size and origin of the most important plant-nutrient discharges,
- to include a mixture of both point source and diffuse-source controls,
- to take account of the user-related water quality objectives,
- to consider zoned rather than uniform treatment.

OPTIONS FOR DISCHARGE STANDARDS

Two options for management of direct waste discharge through establishing standards are:

1. To specify the quality of the **effluent or waste stream** at the point of discharge as is the case for the current licence system.

2. Alternatively, to specify levels of key parameters that must not be exceeded in **receiving waters** within the vicinity of a development.

These are not mutually exclusive. The advantages and disadvantages of each of these options are discussed below. It is inappropriate for GBRMPA to dictate what technology should be used in a treatment plant. The discharge standard should be set but the choice of technology and methods used to meet those standards are for the permittee to make.

Option One

Specification of the quality of effluent in terms of BOD and NFR, at the point of discharge has been applied to date in most Queensland licences and GBRMPA permits.

(a) Advantages: As the level and technology of waste treatment applied makes it relatively easy to predict the eventual effluent quality, this is the most efficient option for management. It is simple to explain to applicants for licences. It is relatively easy and inexpensive to monitor effluent quality as sampling is undertaken at the treatment system, thus also facilitating enforcement.

(b) Disadvantages: It is not a flexible system in that it does not allow for varying wastes and varying capacity for assimilation in receiving waters.

(c) Other comments: In most environmentally sensitive environments, receiving water quality is used to help determine the standards and thus the type of treatment process advisable. In the GBR Marine Park, sufficient data are not yet available to specify N and P standards in effluent based on tolerance levels of reef biota. However, initially standards based on type of treatment most commonly used at present (secondary), could be adopted. This would require standards of 25 mg/l N and 10 mg/l P in addition to 20 mg/l BOD and 30 mg/l NFR not to be exceeded.

(d) Monitoring: At both existing and new treatment facilities, operators would be required to sample effluent and analyse for nutrients in the system taking into account peak and low use times to ensure the system is functioning properly in compliance with standards. This will also add information on nutrient loading into the Marine Park and give an indication of variability in a treatment system over time, and between treatment systems.

Option Two

The overall effect of defining a water quality standard to be met in the receiving waters is to make the developer or operator responsible for water quality in a defined area of the Marine Park.

(a) Advantages: This system allows for flexibility in treatment solutions and ensures local responsibility is taken for "non-point" discharge through erosion and run-off.

(b) Disadvantages: Determining the receiving water standards can be a long and expensive task and legal enforcement is likewise difficult and costly. Even though it would not be the case, water quality managers would have to be prepared for the claim from operators that standards are not applied consistently. The other real criticism is that it would be impossible to <u>prove</u> the source of nutrient levels that are too high.

(c) Other Comments: Bell et al (1987) recommended that water quality standards should be established based on mean ambient levels in receiving waters in the vicinity of a resort at the initial point of dilution and based on the estimated tolerance levels of corals. At present, there is insufficient information available regarding tolerance levels of different types of corals to nutrients.

The Government of South Australia (1989) has recently proposed that criteria for nutrients be based on observations of natural waters, and samples taken to test compliance with any criteria should be at least 200 metres from any outfall, and be free from bottom sediment.

Most logically, the mean ambient water quality at the nearest reef potentially subjected to the effluent discharge needs to be maintained or improved. Circulation studies are required to determine water movement around the proposed discharge point. The objectives of such studies are to:

- ensure that maximum diffusion is obtained in the receiving waters in a variety of wind and tide conditions,
- situate the discharge pipe where there is the minimum opportunity for diluted effluent to flow to the reef edge, and

- determine where water quality measurements should be taken, if diluted effluent circulates to the reef edge under any conditions.

A statistically sound water quality study including assessment of temporal and spatial variability would need to be undertaken.

The waste treatment process is likely to be acceptable to the Authority if circulation, dilution, dispersion, and water quality studies indicate that ambient levels of nutrients at the reef edge most likely to be affected, will not be increased as a result of the proposed treatment process.

If the proposed waste treatment process does not achieve this, there are a number of options for the permittee:

- a longer discharge pipe, with longer diffuser, at greater depth
- nutrient removal if not already considered
- reduction of nutrient load production at the site: use of phosphorus free detergents, laundry to be done on mainland (if an island), more food preparation done on mainland, limitation on number of visitors.
- removal of sewage waste from site (to mainland) for processing.

Sufficient monitoring would be required to prove that the proponent's claims/calculations are valid. This would be determined at the time of permit assessment and would be at the proponent's cost.

(d) Monitoring : At a proposed development, time averaged data over 6 months, with no fewer than 6 collection periods, including replicates, should be sufficient to establish the mean ambient water quality. After construction of the treatment facility and outfall, measurements could be made quarterly over the next year to compare with ambient levels. If the results of the year's sampling indicated that water quality at the reef edge was significantly different statistically, remedial action would need to be taken.

As inclusion of the nutrient removal process is estimated to incur an increased cost of 20% of the total treatment process, this may be a financially viable alternative in a sensitive environment where costly monitoring might be required if secondary treatment alone was used.

While the cost of monitoring and possible later incorporation of nutrient removal is minimal compared to the cost of a large treatment system or the overall cost of construction of a large resort (pop 3000), it could be unrealistic for a small resort. Requirements for monitoring need to take this into account.

If local ambient water quality conditions are being met, thus having little impact on local reefs, there is still the possibility of island point source discharges adding to the overall nutrient level in the GBR. This would have to be dealt with in the context of overall regional levels, after further research and monitoring is completed.

MANAGEMENT RECOMMENDATIONS

1. On the basis of preliminary GBR data compared with overseas data on nutrient effects on reefs, a major long-term objective of the Authority should be that present levels of nutrients in GBR waters not be allowed to increase through human use. Where existing levels near coral reefs are shown to be higher than those which are compatible with coral health or which have occurred historically, the levels should be reduced to levels which are compatible to coral health.

2. Attention to direct waste discharge into the Marine Park needs to be given a higher priority by appropriate government agencies and by tourist operations. It is reasonable to expect that, where necessary, upgrading of treatment facilities will be phased in over a period of time to take account of the facility cost, operator training requirements, and to provide time for feedback from monitoring programs.

3. Applications for permits to discharge waste into the Marine Park will be considered on a site specific basis, taking into account proximity of environmentally sensitive sites, hydrodynamics, ambient water quality, and present condition of any sensitive communities.

4. Applicants for new discharges should be required to install the equivalent of secondary treatment with provision for nutrient removal to be added at a later stage. In environmentally sensitive areas, applicants should be required to establish that the proposed treatment process and dispersion characteristics are such that ambient nutrient levels at adjacent reefs are not increased. If secondary treatment and use of "prevention" and "dilution" techniques do not meet established criteria, nutrient removal should be considered.

5. To accurately determine characteristics of effluent from tourist operations, all permittees will be required to monitor nitrogen and phosphorus in effluent on a fortnightly basis at their expense over the next year. Additional monitoring parameters may also be required in consultation with Queensland government agencies. Sampling will be designed to be representative taking into account peak discharges.

6. A thorough assessment of existing treatment plants which discharge into the Marine Park, should be undertaken, with site visits to inspect treatment plant maintenance, outfall location, and effects on adjacent sensitive sites.

7. The current discharge of waste water into the Marine Park should be considered in comparison with other options.

RECOMMENDED GUIDELINES

Recommended Information Required in a New Permit Application.

GBRMP Act Regulation 15 specifies minimum information required in a waste discharge application: location of discharge, alternatives to the discharge or discharge location, nature of material, rate of discharge, and means of transport, if required. In addition each application is a special case and information required may be varied to address its unique situation.

Generally the following is required:

Description of proposed/actual treatment plant, ie. design type, capability of N and P removal, capacity.

Drawings of the proposed/actual outfall site and surrounding area, showing proximity to fringing and other reefs.

Justification of ocean discharge option; evidence of consideration and advisability of irrigation of waste.

Details of proposed outfall pipe, materials used, how anchored, depth below low tide datum.

Details of proposed diffuser attachment and estimate of dilution rate.

Justification of outfall site and discussion of possible alternative outfall sites: information on hydrodynamics of proposed outfall area, indicating fate of effluent plume (possible use of dye studies, current meters, etc.)

Proposed arrangements for sludge disposal.

Location and brief description of nearby fringing reefs, other sensitive sites, ie. mangroves, seagrasses.

Ambient water quality (N&P) in location of outfall and at sensitive sites over a range of wind and tide conditions.

Recommended Conditions for Sewage Discharge Permits

Conditions may be varied to reflect special features of an application.

Compulsory

To the greatest extent possible, the outfall site to be "downstream" from the nearest reef or other sensitive sites if at all possible. This is to be established by hydrodynamic measurements.

Average effluent quality not to exceed 20 mg/l BOD, 30 mg/l NFR, 25 mg/l N, and 10 mg/l P, with nutrient levels to be reduced if feasible. Nutrient removal to be required only where it is necessary to maintain established criteria once they are determined. Criteria are determined by measurement of background levels and allowing for no detectable change in nutrients under normal conditions.

Sludge waste is not to be discharged or dumped in the Marine Park.

Sampling of effluent quality at waste treatment system on regular basis. Results to be reported to GBRMPA, and QDEH. Parameters to be measured are BOD, NFR , total N, total P, salinity (if not fresh water).

Optional

Sampling of receiving waters quarterly for the first year at sites to be determined if no nutrient removal and environmentally sensitive location. Parameters to be measured are salinity, temperature, total N, total P, suspended sediments, chlorophyll a. Techniques to be agreed with GBRMPA.

The outfall site to be as deep below the surface as possible, preferably at least 10 metres below low tide datum. Diffuser of at least 10 m length to be attached to outfall pipe. To be determined by appropriate studies.

INCENTIVES TO TOURIST OPERATORS

1. Maintenance/improvement of quality of adjacent reef.
2. Reduction in short and long-term monitoring requirements.
3. Introduction of a GBRMP environmental rating of tourist facilities should be introduced based primarily on criteria related to degree of modification of the Marine Park and environmental interpretation offered. Factors could include: elements of waste discharge, garbage disposal, fish feeding, marina developments, pontoon moorings; and associated operator-sponsored research and interpretation programs.

4. Adoption of environmental ethic/care of reef theme in the resort marketing strategy should appeal to an ever-increasing segment of the tourist population.

SUMMARY: Section Three

The objective of the proposed recommendations is to minimise the effects of nutrients from point source discharge on reef biota. Various methods of lowering use of nutrients, sewage treatment and disposal are discussed in relation to reducing nutrient load on sensitive sites adjacent to waste discharges. Because of the extra cost and trained personnel required, nutrient removal as a treatment process is not recommended unless other options fail to achieve desired water quality at the sensitive site. Desired water quality is defined by either the ambient levels of BOD, NFR, Total N, and Total P, or those levels which are shown to be compatible with coral health. A thorough assessment of existing waste discharges into the Marine Park should be undertaken. It is reasonable to expect that, where necessary, upgrading of treatment facilities will be phased in over a period of time to take account of costs. training, and feedback from monitoring. Details of information required in a permit application for waste discharge are provided and options for permit conditions described.

Table 1. Summary of Case Studies

Location	Reference	Effects on Biota	Water Quality	Reported Cause of High Nutrients
Bermuda	Bach & Josselyn, 1978,9 Lapointe & O'Connell 1988	dense Cladophora (algal) mats	$N0_2$ - .7 µM $N0_3$ - .3 µM PO_4 - .03µM NH_4 - 2.0 µM Several times higher in algal mat; total N 2.4 µM P elevated	N-rich groundwaters into Bay
Grand Cayman	Rose & Risk 1985	. sponge increase . dead coral	6 fold increase in bacteria biomass	untreated sewage from turtle farm discharged at rate of 162m^3/hr onto fringing reef
Florida Keys	Lapointe 1989	. Phormidian, micro-filamentous blue-green algae: . corals with black band disease	not provided	8 million gal/day raw sewage upstream
Ishigaki Is, Japan	Kuhlman 1988	. low coral cover and diversity . white band disease in corals . overgrowth by algae, zoanthids, sponges . increased crown-of-thorns	not provided	. siltation and agricultural chemical runoff . depending on crop, fertilisers rich in N,P & K are applied at rate of 1200-2400 kg/ha
Aqaba, Red Sea	Walker & Ormond, 1982	. coral death . algal growth . increased sea urchins	sewage area PO_4 0.96 µM control area PO_4 0.26 µM	. phosphate dust from shipping . sewage

Barbados, West Coast	Tomascik & Sanders, 1985	low coral growth rate	. attributed to increased SPM SPM 4.3 - 7.3 mg/l PO_4 0.2 -.06 µg/l NO_3 .4 - 4.4 µg/l NO_2 .04 - 0.7 µg/l NH_3 .5 - 2.6 µg/l oceanic levels of PO_4 .03 µg/l	septic/groundwater + industrial effluent + treated sewage = 8.5 million litres/day
Alicante Bay, Spain	Zoffman et al, 1989	. degradation of local ecology . deterionation of water quality aesthetic	40-128 µg/l P - near outlet 150-450 µg/l N 20 µg/l P - at control site 85 µg/l N	untreated sewage at 1000m^3/hr later treated sewage and numerous small direct untreated discharges
Kanoehe Bay	Maragos 1972, 1985 Smith et al 1981 Kinsey 1988 Marszulek, 1987	. decreased coral cover . increased green algae, Dictyosphaeria cavernosa . increased benthic filter feeders (sponges and sea cucumbers)	Bay Means *(see below) (Smith et al 1981)	. runoff and groundwater = 8.6 mill m^3/month . sewage=.5 mill m^3/month (or 7.5 mill gal/day or 20000 m^3/day . est. loading: 5.2 Moles/day P 57.5 Moles/day N 245 Moles/day Si
Tonga	Zann, 1988	shift from coral dominated system to algal/seagrass	NO_3 .4 - .9 µM NH_4 .05 - 7 DON 10 - 23 Tot N 13 - 34 PO_4 .04 - .5 Chloro 1.2 - 1.9	sewage outfall, groundwater, storm drains, surface run-off

Green Island	Kuchler,1978 Allan & Johns, 1989 Van Woesik, 1990 Steven et al, 1989	increase seagrass low coral cover 2 visitations by COT	depending on location, range of means was: NO_2 & NO_3 .23 - .38 µM NH_4 .39 - 1.33 DIN .78 - 1.69 Part N 1.1 - 3.9 Tot N 5.8 - 9.0 PO_4 .13 - .21 Tot P .3 - 5 BOD .3 - 1.4µg/l Chloro. 3.5 µg/l (Steven et al 1989)	. untreated resort, public toilet and aquaria sewage . contaminated groundwater
Hayman Island	Steven & Van Woesik, 1990	in vicinity of discharge, low coral cover, largest turnover coral species, minimal recruitment	range of means dep. on location NO_3 .07 - .6 µM NO_2 .01 - 1.03 NH_4 1.3 - 15.4 P-PO_4 .5 - .77	. reef recovering from marina dredging . secondary treated sewage

* Kanoehe Bay - Means (µM)

	Bay		Ocean	
	Pre	Post	Pre	Post
NO_3	0.41	0.37	0.14	
NH_4	0.67	0.43	0.47	
DIN	1.08	0.80	0.61	
DON	4.7	5.7	4.5	
Part N		2.8	2.07	0.44
Tot N		8.6	8.6	5.6
(PO_4)				
DIP	0.33	0.11	0.13	
DOP	0.30	0.20	0.30	
Part P		0.12	0.08	0.01
Tot P	0.75	0.39	0.44	
Chlor. µg/l		1.13	0.78	

Smith et al (1981)

Table 2. **GBR Water Quality Summary**

AREA	Chlorophyll-a (µg/l)	NO2-N	NO3-N	NH4-N	PO4-P	Si(OH)4-Si	Sus.Sed (mg/l)
				µM			
Inter-reef water column (Furnas et al 1990)							
Mean Winter	0.24	0.01	0.03	0.10	0.18	1.11	
Mean Summer	0.37	0.06	0.03	0.16	0.16	1.03	
Reef lagoon (Furnas et al 1990)							
Mean Winter	0.18	0.04	0.25	0.14	0.15	1.31	
Mean Summer	0.71	0.05	0.60	0.17	0.20	0.10	
Whitsundays (Furnas et al 1988)							
Mean	1.17	0.00	0.20	0.22	0.23	1.72	
Shelf (Central & Southern GBR (Furnas et al 1988)	0.68	0.00	0.11	0.12	0.16	0.93	
Barron R-Green Is (Brady 1989)							
Mean		0.16	1.62	0.10	0.20		
Range		<.10-.31	0.09-14.2	0.04-0.18	0.09-.52		

AREA	Chlorophyll-a (µg/l)	NO2-N	NO3-N	NH4-N	PO4-P	Si(OH)4-Si	Sus.Sed (mg/l)
					µM		
Green Is. (Brady 1990) Mean			0.34	0.31	0.15		
Range		<0.01-0.05	0.09-0.45	0.07-.71	.07-.25		
Green Is. 24 hr Study (Steven et al	3.48		0.32	0.73.	0.17		2.0
1989)	0.49-8.66		0.13-0.54	0.01-3.71	0.01-0.41		1.4-3.4
Cleveland Bay (Walker & O'Donnell 1981)			0.26		0.20		
Hayman Is. (1) (Blake 1989) Range	0.22-0.58	<0.01-0.01	0.24-0.36	0.14-2.56		1.60-5.23	
Hayman Is. (2) (Blake 1989)	0.22-0.34	<.01	0.12-0.19	0.17-2.37			1.27-2.95
Hayman Island (Steven & Van Woesik 1989) Range of Means	0.14-0.64	0.01-1.03	0.07-0.6	1.3-15.4	0.5-0.77		
John Brewer Reef (Jones et al 1989 Range of Means	0.22-0.42	0.21-0.48	0.22-0.29	2.61-4.01			

AREA	Chlorophyll-a (μg/l)	NO2-N	NO3-N	NH4-N	PO4-P μM	Si(OH)4-Si	Sus.Sed (mg/l)
Davies Reef Lagoon (Furnas et al 1990)							
Mean Winter	0.18	0.04	0.25	0.14	0.15		
Mean Summer	0.71	0.05	0.60	0.17	0.20		
Nelly Bay (Brodie et al 1989)							
Mean	0.59		0.86	0.48	0.29	3.4	3.95
Range	0.05-2.0		0.21-2.1	0.07-2.8	0.03-4.8	1.6-7.3	0.3-47.2
Far Northern GBR (Furnas 1990) range of Means across depths							
- outer shelf reef	0.07	0.02	0.03-0.04	0.02-0.03	0.02-0.03	.82-.83	
- inner shelf reef	0.17-.21	0.02	0.03-0.04	0.07	0.06	2.84-2.99	

Table 3. Comparison of GBR Data with Overseas Data

	Nitrate & Nitrite µM	PO4 µM
Central GBR (Furnas et al 1988)	.11	.16
Kaneohe Bay (Smith et al 1981) (eutrophication levels)	.41	.33
Barbados (Tomascik & Sanders 1985) (troublesome levels)	0.4-4.4	0.2-0.6
Caribbean background levels (Tomascik & Sanders 1985)	0.03	
Green Island (Steven et al 1989)	.23-.38	.13-.21
Hayman Island (Blake 1989)	.25-.37	
Whitsundays (Furnas et al 1988)	.20	.23

Table 4. Status of Island Discharges Within the Marine Park

Location /Status	Standards m^3/day	Flow Rate	Est N Load	Est P Load
			(tonnes per year)	
Current Discharge to Marine Park				
Bedarra (2 plants)	secondary (AAT plant-activated sludge)	60	0.70	0.15
Hayman	secondary (oxidation ditch)	450 (sewage) 3400 (desal brine & cooling water 6500 (air cond cooling water	4.9	1.1
Green	septic tank discharges into Marine Park to be upgraded	100	8.3	1.2
Heron	secondary: on land disposal (unlicensed); kitchen waste off reef edge; desalination plant	100,000 l/day (desal. water)		
Lindeman	secondary (AAT plant-activated sludge)	400	4.3	1.0
Keppel	secondary	500		
John Brewer Reef hotel (now removed from GBR)	secondary: disposal by barge (either off reef edge or mainland)	5000 T/month		
South Molle	secondary (Activated sludge)	400	4.3	1.0
Contiki Whitsunday, Long Is.	secondary (AAT plant-activated sludge)	360	3.9	0.9
Hamilton	secondary	800	8.8	2.0

Applications Current

Daydream	tertiary under consideration			
Paradise Bay, Long Island	secondary, with provision for tertiary			
Hinchinbrook	secondary (Activated sludge)	40	0.4	0.1
Lady Elliott	secondary (land disposal)			

Not Requiring GBRMP Permits

Brampton	secondary (land disposal - overflow only during extreme wet weather)			
Hook	septic			
Orpheus	septic			
Dunk	secondary (land disposal - to be upgraded)			
Magnetic	secondary; land disposal for part; septic			
Lizard	septic; land disposal			

Note : Total Nitrogen and total Phosphorus concentrations in domestic wastewater are on average up to about 30 mg/l and 7 mg/l respectively, although significant variations can occur, depending on the wastewater source and the type of treatment provided. Activated sludge plants which are operated in denitrification mode will reduce nitrogen concentrations, but will not have much influence on phosphorus. Fluctuations in flow volume and nutrient concentration tend to be attenuated in larger treatment plants. Small plants which serve variable populations (eg. island resorts) are likely to have the greatest variations. Treatment plants which are situated in high rainfall areas may discharge lower nutrient concentrations due to stormwater infiltration into sewers.

An EP (equivalent population) figure may be used as a design parameter in the absence of actual flow data. An average daily dry weather flow (ADWF) of 225-275 litres per person per day of domestic sewage is commonly adopted. Peak dry weather flow at small treatment plants (<1000 persons) may be up to 2.2 times the ADWF. It is likely that at some island resort treatment plants, this factor may be exceeded because of seasonal influences. An example of this can be seen in recent data on flows and nutrient concentrations at Green Island. The importance of incorporating peak dry weather flow data into treatment plant design increases in the case of smaller plants.

Without supporting analytical and flow data, it is difficult to arrive at meaningful estimated nutrient loadings using only licensed flow rates and average nutrient concentrations, because of these inherent variations. Such calculations may be used to define the order of magnitude involved, but should be viewed with caution (Queensland Department of Environment and Conservation, 1989a)

Table 5. Volumes of N&P Loads, Sewage Discharges to North Queensland Waters.

LOCATION	RECEIVING WATER	VOLUME (m^3/d)	LOADS (tonnes/yr)	
			N	P
Port Douglas	Dicksons Inlet	2,800	31	8
Cairns North	Barron R.	10,700	117	31
Cairns South	Smiths Ck	8,800	96	25
Edmonton	Skeleton Ck	2,000	21	6
Gordonvale	Mulgrave R.	1,400	15	4
Babinda	Babinda Ck	1,700	19	5
Innisfail	Ninds Ck	3,400	37	10
Tully	Tully R.	1,500	16	4
Ingham	Herbert R.	5,000	55	15
Condon	Bohle R.	3,700	41	11
Townsville N	Bohle R.	3,400	37	10
Townsville S	Cleveland Bay	30,000	328	87
Ayr	Kalamia Ck			
Home Hill	Burdekin R.	2,200	24	6
Bowen	Port Denison	2,000	21	6
Proserpine	Proserpine R.	1,700	19	5
Cannonvale	Pioneer Bay	2,000	21	6
Mackay	Reliance Ck	1,000	11	3
TOTAL		83,300	909	242

(Queensland Department of Environment and Conservation, 1989b, with permission)

Table 6. Comparative P loads: Riverine Stormflow, Urban Sewage Discharge, Island Resort.

	Estimated Phosphorus Load (tonnes per year)
Barron River	421.9
Cairns sewage discharge	56.0
Green Island	1.2

(figures compiled from Tables 4, 5, and 7)

Table 7. Drainage basin area, mean annual runoff and estimated mean annual riverine stormflow of total phosphorus load, adjacent to Cairns Section of Marine Park.

Drainage Basin	Area (km^2)	Mean Annual Runoff (mm)	80% of Runoff (kg/ km^{2}mm^{-1})	Export Coef.	Total phosphorus load (tonnes)
Jeannie	1878	*657	526	0.54	533.0
Endeavour	1100	946	757	0.54	449.5
	1100	2799	2239	0.54	1330.1
Daintree	2125	1513	1210	0.54	1388.9
Mossman	490	1200	960	0.54	254.0
Barron	2175	449	359	0.54	421.9
Mulgrave-Russell	2020	3441	2753	0.54	3002.8
Johnstone	2330	1964	1571	0.54	1976.9
				Total	9357.1

* Mean of Jeannie River (531 mm) and McIvor River (783 mm).
(P. Cosser,1988 a)

Table 8. Resulting N & P for Various Levels of Sewage Treatment

	BOD (mg/l)	NFR (mg/l)	N (mg/l)	P (mg/l)
Primary	300	300		
Secondary	20	30	20-30	7-10
N & P Removal	10	10	7-10	1
Suggested GBR coral tolerance level, based on % increase over background (Bell et al 1989)			15.4 μg/l	7.5 μg/l

Table 9. Required Dilution Ratios for Primary, Secondary, and Tertiary (1°,2 and 3)Treated Sewage for Waters of the Great Barrier Reef, Australia

Contaminant	$C_{discharge}$ Concentration in Sewage			$C_{tolerance}$ (% Increase over background	$C_{background}$ Background	F Required Dilution Ratios		
	1^{o}	2^{o}	3^{o}	Tolerance Level		1^{o}	2^{o}	3^{o}
BOD_5 (mg/l)	300	20	10	0.78 (10%)	0.71^{+}	4300	270	130
NFR (mg/l)	300	30	10	3.3 (10%)	3.0^{++}	1000	90	20
Inorganic-N (µg/l)	50000	20000	2000	15.4 (10%)	14.0^{**}	36000	14000	1400
$P\text{-}PO_4$ (µg/l)	10000	10000	1000	7.5 (10%)	6.8^{**}	14000	14000	1400
Chlorine (µg/l)	700	<700	<700	50.0	0.0	13	<13	<13
Salinity (ppt)	1	1	1	30.0	35.0	6	6	6
Pesticides (µg/l)	1	<1	<1	10.0	0.0	0.0	0	0
Heavy Metals (µg/l)								
Hg	3	<3	<3	0.1	0.0	30	<30	<30
Pb	70	<70	<70	10.0	<0.06	6	<6	<6
Zn	70	<70	<70	20.0	0.13	2.5	<2.5	<2.5
Cu	150	<150	<150	1.0	0.22	190	<190	<190
Ni	50	<50	<50	2.0	0.11	25	<25	<25

*	Total oxidiseable nitrogen
**	Values for Lizard Island
+	Barbados value

(Bell et al, 1989)

Table 10. Sewage Treatment Works Augmentations

	Augmentation Date	Treatment (Post Aug).	Flow kl/day	Receiving Waters
Thredbo	1986	*1,2,3,4,5	1500	Thredbo River
Skitube (Bullocks Flat)	1986	*1,2,3,4	250	Thredbo River
Lake Crackenback	1989	*6	125	Wollondibby catchment or below Jindabyne dam
Charlottes Pass	1988/89	*1,2,3,4	230	Spencers Creek
Smiggin Holes	1986	Pump to Perisher	N/A	Perisher Creek
Guthega	1986	Pump to Perisher	N/A	Perisher Creek
Blue Cow Creek	1987	Pump to Perisher	N/A	Perisher Creek
Sponars	1987	*1,2,3	24	Diggers Creek
Sawpit Creek	1989	*1,2,3,4	90	Sawpit Creek
Wilsons Valley	1990	*1,2,3	60	Sawpit Creek

*
1 Nitrification
2 Nutrient removal
3 Ponding and ultraviolot disinfection
4 Stand-by power
5 Telemetering alarm system
6 Secondary treatment and discharge to land irrigation or pump to Jindabyne

(State Pollution Control Commission, NSW, 1988)

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APPENDIX ONE: EXPLANATION OF TERMINOLOGY

NITROGEN

Nitrogen (N) is composed of organic and inorganic N. In freshwater, organic N is the dominant fraction. A ratio of 10:1 organic to inorganic is usual. Though some algae can use some organic N from the water column, organic N is not largely immediately biologically available.

Inorganic forms include nitrate (NO_3), nitrite (NO_2), ammonia (NH_3) and molecular N (N_2). The major species of nitrogen in the environment are interrelated by a series of transformations that comprise the nitrogen cycle. In summary, organic N is mineralised to ammonia, and ammonia is subsequently oxidised to nitrite and nitrate. Nitrite does not persist for long so the sum of nitrite and nitrate is often used in water quality measurements. All three may be high in sewage. Organic N is always present, but the relative amounts of ammonia and nitrate after sewage treatment, depend on the treatment process.

Ammonia

Natural sources of ammonia include biological litter, animal waste, and forest fires. Ammonia associated with clay minerals enters the aquatic environment through soil erosion. Commercial fertilisers frequently contain highly soluble ammonia and ammonium salts. When the concentration of such compounds exceeds the immediate plant requirements, the excess is transported into the aquatic system.

Ammonia in water may form complexes with metal ions. It may be adsorbed onto suspended and bed sediments and to colloidal particles. Ammonia may be exchanged between sediments and overlying water.

Freshwater typically contains ammonia in concentrations below 0.1 mg/litre.

Nitrate

Human and animal wastes are a principal anthropogenic input of nitrate to aquatic systems. Soil leaching where inorganic nitrate fertilisers are used also contributes nitrates to river waters, with concentrations tending to be highest during spring and early summer.

Surface waters contain at least trace levels of nitrates, varying from less than 1 mg/litre to 5 mg/litre. Rainwater may contain a nitrate concentration of 0.2 mg/litre.

Nitrite

The presence of nitrite indicates active biological processes influenced by organic pollution. Because nitrites are rapidly oxidised to nitrates, they are seldom present in surface waters in significant concentrations. Nitrite levels are usually in the order of 1 μg/litre to 1.0 mg/litre in freshwater.

DISSOLVED OXYGEN

An adequate supply of dissolved oxygen is essential for the maintenance of purification processes in natural water systems and waste treatment plants. By measuring the dissolved oxygen content, the effects of oxidizable wastes on receiving waters and the efficiency of waste treatment may be assessed.

The decomposition of organic matter and oxidation of inorganic wastes may reduce dissolved oxygen levels, sometimes leading to potentially anaerobic conditions. Decomposition of organic matter is a major cause of oxygen depletion, and is most intense at the sediment-water interface.

Large variations exist seasonally and geographically, in part a result of variations in temperature, salinity, turbulence, photosynthetic activity and river discharge.

The concentration of dissolved oxygen in natural surface waters is usually less than 10 mg/litre.

PHOSPHORUS

Phosphorus may be removed from igneous and sedimentary rocks by leaching and weathering. The decomposition of organic matter is another source of phosphorus. Domestic and industrial effluents and agricultural drainage from fertilised land contribute phosphorus to waters, in terms of sewage, fertilisers, detergents, pesticides and many other forms.

Phosphorus is continually changing in the aquatic environment. It is rarely found in high concentrations in surface water because it is actively taken up by plants. The exchange of phosphorus between sediments and water is mobilised by bacteria, turbulence, and other factors.

Phosphorus concentrations in rainwater can vary from 0.03 in background areas to 0.1 mg/litre in urban areas. Marine waters average 0.02 mg/litre in urban areas. Concentration of phosphorus ranges from 2800 to 4000 mg/litre in marine algae (Environment Canada, 1987).

Concentrations of phosphate between 0.01 and 0.05 mg/litre are generally found in surface waters. Two basic classes of phosphates are recognised:

- inorganic phosphates
- organic phosphates

Inorganic Phosphate

The negatively charged phosphate ion reacts readily with: positively charged surfaces such as clay particles; some metal ions; and oxides and hydrous oxides of Fe and Al. As such, inorganic P in water occurs as dissolved orthophosphates and phosphates associated with colloidal particles, either suspended or in sediments.

Organic Phosphate

Organic phosphates are those phosphates associated with carbon compounds and usually originate through biotic synthesis, detergents excepted. Organic P may constitute a significant fraction of the total soil phosphorus pool. Organic phosphates may occur in solution or in association with particulates. Drainage water contains both forms.

A secondary distinction is made between particulate and dissolved forms, the division conventionally being made by filtration through a 0.45 um membrane. Overlap can occur between the different forms due to separation and analytical techniques.

Total Phosphorus (TP)

All the P in the unfiltered sample, except that in minerals resistant to the digestion method. Measured directly.

Total Dissolved Phosphorus (TDP)

All the P in the filtrate after 0.45 um filtration. The sum of both dissolved organic and dissolved inorganic phosphates. Measured directly. It is the most significant form in oceanic waters.

Dissolved Reactive Phosphorus (DRP in some cases is represented as P-PO$_4$)

P in filtrate reacts with colorimetric reagents. May include both orthophosphate and dissolved organic phosphates. Measured directly. DRP may be the dominant form in offshore waters, but both DRP and dissolved organic phosphorus (DOP) can be significant in sewage effluent. For mass balance models TP is necessary, whereas for correlations with algae biomass DRP may be the best. As a result of rapid cycling between DRP DOP, DRP is not always a good indicator of biologically available P.

Typical P-PO$_4$ in the GBR ranges from 0.11 to 0.26 um.

Dissolved Organic Phosphorus (DOP)

The organic phosphorus fraction, including detergent phosphates. Determined indirectly as DOP = TDP - DRP

Particulate Phosphorus (PP)

All the P in particulate form, both organic and inorganic. Determined indirectly as: PP = TP - TDP.

PP is high in flood runoff but only a fraction is biologically available. It is of less significance in oceanic waters.

The usefulness of differentiating between fractions depends on the type of water and objectives of monitoring. TP, PP, and TDP should be used as a minimum.

BIOLOGICAL OXYGEN DEMAND (BOD)

The biological oxygen demand of water may be defined as the amount of oxygen required for aerobic micro-organisms to oxidize organic matter to a stable inorganic form. The determination of BOD is an empirical test in which standardized laboratory procedures are used to quantify the relative oxygen requirement of a water sample. The accepted procedure is to measure the decrease in oxygen content in milligrams per litre of a sample of water in the dark at 20 degrees C after 5 days, by which time 70% of the final value has usually been reached. This is usually termed as BOD_5 Typical secondary treated effluent has a maximum of 20 mg/l BOD_5

MEASUREMENTS USED

In this report, several different terms of measurement are used. The relationship between them and alternative ways of expressing water quality measurements are described.

Some Basics

1 g = 1000 mg = 1 000 000 ug = 1×10^{-6} g

atomic weights of relevant elements:

H	1
N	14
P	31
O	16

1 molar (M) = 1 mole $litre^{-1}$
= 1 mole / litre
= 1 g atom / litre

Because one mole expresses molecular weight in grams, then
1 M = 1 mole / litre of PO_4= 95 g / litre PO_4
and 1mM = 1m mole / litre = 95 mg / litre PO_4
1 µM = 1 u mole / litre or 95 ug / litre or 9.5×10^{-5} g / litre PO_4

and 95 ug / litre PO_4= 31 ug / litre P

1 u molar = 1 umole / litre = 1 ug atom / litre = 62 ug / litre NO_3
= 18 ug / litre NH_4
= 14 ug / litre N

1 mg / m^3(cubic metre) = 1 ug / litre, oceanic water

1 m^3= 1 tonne freshwater = 1.025 tonne saltwater

OTHER TERMS

Standards

Legally enforceable levels of parameters established by an authority. They may be arbitrarily established in the absence of technical data and may include a factor of safety.

Criteria

The scientific yardsticks upon which a decision or judgement may be made concerning the ability of water of a given quality to support a designated beneficial use (Department of Conservation and Environment, W.A., 1981).

Point Source Discharge

Those discharges which discharge directly to the sea, with a readily identified origin, not necessarily restricted to discharge through a pipeline.

Diffuse Source Discharge

A discharge from stormwater, rivers and creeks draining agricultural, urban and industrial run-off, septic tanks and rubbish dumps.

Pollution and Criteria for Point Sources

Definition of pollution of the marine environment adopted by UN agencies is:

> "The introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) which results in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities."
>
> (Government of South Australia, 1989)

This implies that many substances may be present in marine waters (often occurring naturally) at levels that do not produce deleterious effects, because the concentrations are within the capacity of the environment to absorb or transform. In fact many substances, such as metals, are necessary - at low concentration - to life, (often as factors in enzyme reactions), but become toxic, by overloading the system, at higher concentrations. To provide a guide to the condition of water, various authorities have published water quality criteria. These are arbitrary figures, derived from research findings, that provide a yardstick to decide whether water may be considered polluted. Any criterion must refer to the possible use of the water - for example, a particular level of copper may make water unsuitable for farming oysters, without impairing it for swimming. Conversely, bacteria may provide extra food for shellfish, but make them unsuitable in turn for human consumption.

Criteria should apply to receiving water, rather than to discharge waters, because the availability of many elements and compounds is a function of characteristics of the waters, such as their pH, temperature, and presence of other chemicals. The form in which metals are available in marine waters - their chemical 'speciation' - is affected particularly by the other salts dissolved in the sea and by the presence of organic "chelators" which can bind the metal, making it less available in dissolved forms, but perhaps more available to (eg.) filter feeding shellfish.

(Government of South Australia, 1989)