MONITORING TREATMENT AND MANAGEMENT OF NUTRIENTS IN WASTEWATER DISCHARGES TO THE GBRMP

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SUMMARY

Runoff and sewage discharges from tourist resorts can cause serious adverse impacts on coral reef communities. These impacts result from both the contaminants contained in the discharges and from the freshwater carrier, itself. Of the many components of sewage, the nutrients nitrogen and phosphorus appear to cause the most severe adverse impacts.' The main effects of nutrients on corals appear to be indirect. The higher nutrient levels result in increased algal growth which can ultimately lead to complete destruction of the delicately balanced coral reef ecosystem, The available evidence implies that denitrification and phosphorus removal are necessary treatment requirements if acceptable levels (after dilution) of these components are to be achieved in the different microenvironments within the discharge region. A significant effort is required to gather the relevant evidence on both the microscale and macroscale effects of nutrients in the GBRMP.

INTRODUCTION

Corals have the ability to thrive in nutrient-poor conditions; Salin (1983) notes they are like oases in the desert. Biologically, coral reefs'. are among the most diverse and most productive of all natural ecosystems. Johannes (1972) notes that these reef communities not only provide a vital source of protein for man but also are a source for a wide range of pharmacologically active compounds. Coral fringing-reefs, atolls and barrier-reefs provide protection from the seas for tropical islands and some continental coastlines and are a valuable tourist resource.

Runoff, groundwater and sewage discharges from tourist developments can adversely impact on coral reef communities. In order to predict the impact of such discharges, one needs to be able to define the tolerance levels of the various contaminants in the discharges. Once derived, these tolerance levels can be used to evaluate various waste-management options. This paper summarises such tolerance level data as derived for the Great Barrier, Reef (GBR) Australia (see Bell et al. 1987 for details). Some available options for the treatment/disposal of waste water discharges are also discussed.'

WASTE DISCHARGE SOURCES AND THEIR IMPACT

The main contaminants in sewage and run-off are listed in Table 1. Typical concentrations for many of these are given in Tables 2 and 5.

It is noted that in regions with significant rainfall the total annual contaminant loads from run-off can greatly exceed those from the discharge of sewage effluent. In this respect it is important to note that the freshwater itself needs to be considered'& a contaminant, because corals have a limited tolerance to hyposalaine conditions. The intensity of run-off events needs also to be considered; one high intensity storm could effectively destroy a nearby fringing reef.

The detrimental effects of sewage, run-off, and even groundwater discharges have been recognised for sometime (eg. see Pastorok and Bilyard, 1985; Tomascik and Sander, 1985). Pastorok and Bilyard (1985) note that coral-reef ecosystems are extrenely sensitive to environmental perturbations and that 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

(iii) the effects of toxic substances may be enhanced by the high water temperatures common in coral reef environments.

The impacts result not only from the contaminants contained in the discharges but also from the freshwater carrier itself. The effects may be localised as is usually the case for BOD and freshwater or may be of a regional nature, as can be the case for nutrients such as nitrogen and phosphorus. Nutrients can affect corals directly through toxic effects or indirectly by promoting a eutrophic environment. Available evidence indicates that many of the impacts associated with waste discharges are synergistic in nature and it appears that the coral ecosystems are relatively intolerant to such disturbances. For example the detrimental impact of a sedimentation load would be magnified if at the same time there is a significant change in the salinity. Another important point to note is that not all impacts will be immediately observable. For example phosphorus levels could be such that deoreased calcification rates are occurring whereby the coral becomes less structurally sound. A single storm event following a prolonged elevation of phosphorus could destroy a reef. Also a combination of increased nutrient levels from continuous waste discharges with a storm run-off event (with the associated freshwater, turbidity, BOD and nutrient loads) could have disastrous effects. In such cases the sudden salinity drop and turbidity increase can cause widespread damage and even mass mortality of existing corals. The main effect of the nutrients is manifested after the event by promoting the growth of opportunistic algae. The algae would prevent the otherwise natural re-establishment of the corals. It is to such a sequence of events that Smith et al. (1981) attribute much of the destruction in Kaneohe Bay. In choosing tolerance levels, therefore, it is advisable to take a conservative approach.

TOLERANCE LEVELS

Tolerance levels for the various contaminants contained in sewage and run-off have been derived (see Bell et al. 1987 for details). These levels are given in Table 5. The derivation of these levels was based mainly on data collected from coral reef-regions around the world and by the use of procedures recommended by the USEPA for marine waters (Water Quality Criteria, 1972). It is stressed that these levels should be used with extreme caution, they are guidelines only.

NUTRIENTS (N and P)

At high levels nutrients such as phosphorus have been noted to have a direct toxic effect on corals (Pastorok and Bilyard, 1985). Kinsey and Davies (1979) conclude from results at Canton Atoll that $P\text{-}PO_4$ levels as low as 0.6 μM can cause significant (>50%) reduction in the calcification

rate (and hence growth rate). On the basis of calcification rates alone it would seem that any significant increase in the average background level -0.2 µM - 0.3 µM in regions of the GBR such as Lizard Island (see Table 3) would lead to significant decreases in calcification rates.

TABLE 1 Direct Discharge Sources,

Source	Main Contaminants
Sewage (including laundry and kitchen waste)	Biological Waste (BOD) Nutrients (eg. N and P) Surfactants, dispersants Suspended Solids Fresh Water (hyposaline)
*Swimming Pools	Chlorine, algicides, freshwater
*Airconditioning Units	Freshwater
Power Houses	Heated water Algicides, antifouling agents, hydrocarbons
*Desalination Plants	Hypersaline water Heated Water
*Industrial Plant	Various (eg. hydrodarbons, heavy metals)
*Laboratories	Chemicals
Run-off	Fresh water Suspended solids Nutrients (eg. N and P) Herbicides from gardens Pesticides Biological Wastes (BOD) Hydrocarbons - from roads

* Note all of these wastes are usually disposed of with sewage

TABLE 2 Typical Average composition of. Urban Run-off

Component	Concentration
BOD_5	30 mg/l
Total - P	0.5 mg/l
Total - N	2 mg/l
Suspended Solids	100 mg/l

TABLE 3 Characteristics of Great Barrier Reef Waters

	North Shelf[2]		Lizard Island[3]		Outer	Central(')	Davies Reef[4]		One Tree[5]	
	Central	Edge	Across Reef	Offshore	Lagoon	Coral Sea	Inside Reef	Outside	Reef	Off Reef
Suspended Particle Matter ($mg l^{-1}$)					3.0[6]					
PO_4-P (μM)			0.22	0.26	0.13	0.13	0.105	0.105		
Total Inorganic-N (NO_x+NH_4) (μM)	0.17*	0.15"	0.99	1.02	0.88**	0.07**	0.39""	0.05""	7.06	0.31
C:N:P atomic ratio in macro-algae (Aug)							485:45.5:1			
Chlorophyll-a ($\mu g l^{-1}$)					0.13	0.39				

NOTES:

* NO_3^- + NO_2^- Aug

** NO_3^- + NO_2^-

(1) Andrews (1983)
(2) Cresswell and Greig (1978)
(3) Crossland and Barnes (1983)
(4) Entch et al. (1983)
(5) Hatcher and Hatcher (1981)
(6) Wolanski et al. (1981)

Also, as noted above, corals have,the ability to thrive in nutrient poor conditions. The long-term addition of relatively small amounts of nutrients can cause major imbalances in existing coral reef, systems by promoting the growth of attached and planktonic algae; Attached,algae affect 'the coral by interfering with the complex life processes which normally occur at the coral surface (eg. by competition for light and nutrients). Planktonic algae also competes for light and nutrients. An additional problem with the planktonic algae is that they add to the sedimentation load . this causes additional stress to some coral species and encourages the growth of benthic filter feeders, which will directly compete with the corals for space.

It is interesting to note that whereas large outfalls in well flushed (ie. turbulent) open-coast regions appear to have minimal (at least in the short term) impact on coral reefs (Pastorok and Bilyard, 1985) small scale discharges if not effectively flushed can cause severe problems eg. Johannes (1972) has reported that seepage from a single cesspool serving a public restroom in Honaunau Bay has brought about the localized degeneration of the nearby coral community. Benthic (attached) algal populations were found to be larger than normal in this area, with much of the coral dead and encrusted. Porites compressa was the coral species found to be most susceptible to the effects of sewage effluent. The Porites genus is the major reef-building coral in Hawaii, and is also very common on the Great Barrier Reef (Domm, 1976).

At this stage the extent of the control that is required for the GBR is unclear but it is recommended that because the background levels are high and are in fact at or around levels that would be considered "polluted" in Barbados or Kaneohe Bay that only small increased in the background levels be accepted. Hence levels corresponding to 10% increases in background $P\text{-}PO_4$ and inorganic-N are taken as the required tolerance levels. These levels would need to be achieved within the initial dilution zone of a submarine outfall if it is located in the vicinity of coral reefs.

Increased phytoplankton growth in turn leads to an increase in the suspended solids concentration and, hence, an increase in the sedimentation load. Sewage and run-off themselves can both contain a significant load of suspended materials. The resultant increase in suspended solids can have a devastating effect on corals. In general the growth of coral is inversely proportional to the turbidity which is related to the suspended solids concentration. This due to the light requirements of the zooxanthellae within the tissue of the reef-building corals. The sediment can indirectly cause stress in corals by reducing light intensity. Sedimentation also affects corals directly by deposition on exposed coral tissue. This sediment must be removed to prevent suffocation , and the effort required by the coral to remove the sediment expends energy. If this is' excessive the coral is stressed.

DISPOSAL OF SEWAGE DISCHARGES

Table 4 summarises the options available to limit the concentrations of nutrients entering the GBRMP from tourist developments.

TABLE 4 Options for Controlling Concentrations of Nutrients in Wastewater Discharges

DILUTION	
TREATMENT	- Physical - Biological - Biological/Chemical - Chemical
CONTROL AT SOURCE	(ie. reduce nutrient entry to waste disposal system by use of phosphorus free detergents for example)

Marine Disposal

Sewage from coastal tourist areas is usually disposed of via submarine outfalls. These outfalls are designed 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. This method often incorporates the use of a diffuser to achieve a localised dilution factor required by the discharge licence. High capacity ocean outfalls can achieve initial dilutions in the range 50 - 200. Subsequent dispersion and decay of wastes occur as the effluent field is transported from the initial discharge zone by the prevailing currents. The dilution rate available in this secondary dispersion zone is usually much less than that in the initial dispersion zone, hence, it is important to achieve as high a dilution as is practicable in the initial dilution zone.

Required Dilution for Coral Reefs

The required dilution ratio (F) for the various contaminants is readily calculated from the discharge concentration data, if the background levels and the tolerance levels are available:

$$F = \frac{C_{discharge} - C_{tolerance}}{C_{tolerance} - C_{background}}$$

The required dilution factors for a number of the components of primary (1^o), secondary (2^o) and tertiary (3^o) treated domestic sewage are given in Table 5. It can readily be seen that of the major components BOD_5 and the nutrients N and P require by far the highest dilutions $(10^3 - 10^5)$. 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 such high dilutions are not normally achieved with conventional outfall systems; an initial dilution of the order of 10^2 is generally considered as being good.

Theoretically high dilutions of the required orders $(10^3 - 10^5)$ could be achieved with correct (non-conventional) diffuser design if suitable locations for discharge were available. Basically what is required is that a diffuser of sufficient length, located at sufficient depth be used. Typically, diffusers of lengths 10 - 100 m set at depths of 10 m or more

TABLE 5 Required Dilution Ratios for 1°, 2°, and 3° Treated Sewage for Waters of the Great Barrier Reef, Australia

Contaminant	$C_{discharge}$ Concentration in Sewage 1°	2°	3°	$C_{tolerance}$ (%Increase over background) Tolerance Level	$C_{background}$ Background Level	F Required Dilution Ratios 1°	2°	3°
BOD_5 (mgl^{-1})	300	20	10	0.78 (10%)	0.71+	4300	270	130
NFR (mgl^{-1})	300	30	10	3.3 (10%)	3.0++	1000	90	20
Inorganic-N (μgl^{-1})	50000	20000	2000	15.4 (10%)	14**	36000	14000	1400
$P-PO_4$ (μgl^{-1})	10000	10000	1000	7.5 (10%)	6.8**	14000	14000	1400
Chlorine (μgl^{-1})	700	<700	<700	50	0.0	13	<13	<13
Salinity (ppt)	1	1	1	30	35	6	6	6
Pesticides (μgl^{-1})	1	<1	<1	10	0.0	0	0	0
Heavy Metals (μgl^{-1})								
Hg	3	<3	<3	0.1	0.0	30	<30	<30
Pb	70	<70	<70	10	<0.06	6	<6	<6
Zn	70	<70	<70	20	0.13	2.5	<2.5	<2.5
Cu	150	<150	<150	1	0.22	190	<190	<190
Ni	50	<50	<50	2	0.11	25	<25	<25

* Total oxidiseable nitrogen
** Values for Lizard Island (see Table 3)
\+ Barbados value
++ Estimated from Wolanski (1981)

may be required to achieve adequate initial dilution. The long diffusion lengths imply the use of additional pumping energy to distribute the discharge stream uniformly along the diffuser.

Control of Phosphorus in Effluent Discharges

The sensitivity of coral ecosystems to increased phosphorus levels requires extremely large dilution factors for effluents from both primary (1^{o}) and secondary (2^{o}) treated sewage (see Table 5). Even the required dilution factor for tertiary treated (3^{o}) sewage is an order of magnitude greater than what is normally achieved with conventional marine outfall systems. To a large extent the phosphorus concentration in the sewage will determine the cost of the treatment/disposal system. Hence, it is worth considering the control of phosphorus at source. It is noted that usually one half the phosphorus in sewage results from the use of detergents and shampoos. Considerable cost savings in the disposal of sewage effluent would be achieved if this source were eliminated by substitution with phosphorus-free washing materials.

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 island resorts is currently practised. However, this disposal option needs to be looked at carefully as there is potential for this sludge to be a significant source of pollution of the groundwater, surface water and ultimately marine water.

Reuse/Recycle of Treated Effluent

Most of the tourist islands in Australia now experience some difficulty in obtaining adequate quantities of good quality water. As the population increases, possibly by more than 400 per cent over the next 25 years, the demand for water will similarly increase to more than 1 000 megalitres per year (Smith, 1985). This growth factor is very much dependent on future commercial decisions affecting tourist development. With the current rate of development of resort islands, the need for increased 'fresh water' supplies is expanding which in turn is increasing the production of hypersaline effluents from desalination plants. There is some potential for re-use of waste water on the islands. Techniques and processes are available to treat waste water to standards which would allow its use for non-domestic purposes such as garden and lawn watering. However, tne impact of such waters on the groundwater system and consequently the marine water system needs to be evaluated.

Run off

Run-off from developed areas and construction areas 'can contribute large loads of suspended solids, nutrients, BOD_5 and toxic organics (eg. pesticides and herbicides) in addition to the extremely large fresh-water load itself. Development per se not only tends to increase the quantity of run-off but also tends to reduce its quality.

Run-off from island resorts is particularly important due to the potential impact of the fresh-water itself on the fringing coral reefs. As mentioned earlier, many coral species are particularly sensitive to low salinity.

Run-off is not easily controlled, especially after the development is complete. Possible strategies to minimise the impact of run-off depend on whether, the situation represents an existing or a new development.

Existing Developments,

Run-off from,existing developments is an extremely serious problem as most developments are located in front of fringing reefs. This run-off needs to be diverted to some type of storage area. The water could then be used on the island or discharged in a controlled manner via submarine outfall so that sufficient dilution could be achieved. Nutrient removal prior to discharge may be required.

It is noted that a principal source of nutrients in run-off is fertilizers. The use of fertilizers should be discouraged.

Future Developments

All future developments should be designed to minimise the impact of run-off on the fringing reefs. One way to ensure this would be to forbid any development near to the fringing reefs. Other factors to be considered are:,

the minimization of disturbances to the existing landscape
the minimization of sealed areas such'as roads and parking areas
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

MANAGEMENT STRATEGY

In proposing a management strategy from nutrient control in the Great Barrier Reef Marine Park, the following premises are assumed:

* Phosphorus and nitrogen are limiting nutrients in GBRMP for corals.,

* Circumstantial evidence implies elevated N and P levels lead to deleterious effects in reef environment

  (a). direct - chronic / synergistic

  (b) indirect - algal growth

* Uncertainty exists as to critical levels of N and P. These levels will be known more exactly in future (ca 0.22 μM PO_4-P)

* Costs of removing N and P from all wastes are high, especially if very low levels of P must be achieved.

* A management strategy is needed in the short term.

* Enforceable management strategies must include measurable water quality and waste discharge variables.

* The GBRMP can be considered as a series of macro regions (eg. Whitsunday Passage) and micro regions (eg. Hamilton Island and surrounding reef areas)

The major current needs are as follows

* Collection of more data and greater interpretation of existing data

  - Gather, coordinate
  - Extend
  - Standardise

* Development of a flexible Management Strategy

  - Existing discharge limitations, use of dilution, proper location of discharge points; probably acceptable in short term but highest risk.

  - Addition of nutrient limitations to discharge streams; more costly, lower risk.

  - Addition of water quality criteria to permits; more difficult (Political, Legislative) but lowest risk.

* Increased educational activity

  - Existing and new developers

  - Visitors

For macroscale regions (ie GBRMP as a whole or for large regions within), the current evidence of nutrient induced problems is insufficient for widespread changes. in legislation. There is a need for a Total P budget over the Marine Park and over specific regions. In addition, there is a need to bring together and extend existing data to establish background levels throughout the GBRMP and specific regions. This will require more sampling and fewer analyses for fewer components.

At the microscale (ie. individual resort or development), a number of specific recommendations can be made:

* For a limited number of existing developments, establish links between specific water quality parameters and reef condition.

* Establish relevant water quality variables in the region of development relative to background levels away from the development.

* Require water quality within a defined region near a development to be maintained at some level relative to the background levels. This can be done by controlling point discharges and controlling run off.

* Establish the importance of runoff and groundwater in affecting fringing reefs.

The management options are summarised in Table 6.

TABLE 6 Management of Nutrients

Macrosystem:	(1) Control Quantities Entering GBRMP
	(2) Control Total Quantities Discharged Within GBRMP
Microsystem:	(1) Control of Specific Point Discharges
	(2) Control of Non-point Discharges
	(3) Control of Water Quality Near Development Relative to Background Levels away from Development.

CONCLUSIONS

Run-off and sewage discharges from tourist resorts have the potential to cause serious adverse impacts on coral-reef communities. The components of most concern are the nutrients nitrogen (N) and phosphorus (P). The available evidence implies that coral reef environments are particularly sensitive to small increases in the background phosphorus level. This means that reefs in the vicinity of small discharges and reefs at some distance from larger discharges can be seriously affected. The available evidence also implies that denitrification and phosphorus removal are necessary treatment requirements if acceptable levels (after dilution) of these components are to be achieved

In regions with significant rainfall, efforts need to be made to ensure that run-off is not discharged in the vicinity of fringing reefs. Run-off should preferably be stored and reused, or discharged through a submarine diffuser. Treatment prior to discharge for the removal of nutrients may be necessary.

REFERENCES

Andrews, J.C. (1983). Water Masses, Nutrient Levels and Seasonal Drift on Outer Central Queensland Shelf (Great Barrier Reef). Aust. J. Mar. Preshw. Res., 34, 821-34.

Banner, A.J. (1974), Kaneohe Bay! Hawaii: Urban Pollution and a Coral Reef Ecosystem. Proc. Second Int. Coral Reef Symposium 2. Great Barrier Reef Committee, Brisbane, Dec. 685-702.

Bell, P.R.F., Greenfield, P.F., Gough, G., Hawker, D. and Connell, D. (1987). Guidelines for Management of Waste Discharges into the Great Barrier Reef Marine Park. Draft Report.

Cresswell, G.R. and Greig, M.A. (1978). Currents and Water Properties During the South-East Trade Wind Season. Aust. J. Mar. Freshw. Res., 29, 345-53.

Crossland, C.J. and Barnes, D.J. (1983). Dissolved Nutrients and Organic Particulates in Water Flowing over Coral Reefs at Lizard Island. Aust. J. Mar. Freshw. Res., 34, 835-44.

Domm, S. (1976). Corals of the Great Barrier Reef, Ure Smith, Sydney.

Entch, B., Boto, K.G., Sim, R.G. and Wellington, J.T. (1983). Phosphorus and Nitrogen in Coral Reef Sediments. Limnol. Oceanogr., 28 (3), 465-576.

Hatcher, A.I. and Hatcher, B.G. 91981). Seasonal and Spatial Variation in Dissolved Inorganic Nitrogen in One Tree Reef Lagoon. Proc. Fourth Int. Coral Reef Symp., Manila, 1, 419-424.

Johannes, R.E. (1972). Coral Reefs and Pollution. In Marine Pollution and Sea Life Ed. Mario Ruivo FAO. Fishing News (Books) Ltd. Surrey, London, 364-374.

Kinsey, D.W. and Davies, P.J. (1979). Effects of Elevated Nitrogen and Phosphorus Levels on Coral Reef Growth. Limnol. Oceanogr., 24 (5), 935-940.

Pastorok, R.A. and Bilyard, G.B. (1985). Effects of Sewage Pollution on Coral-Reef Communities. Marine Ecology, 21, 175-189.

Salin, R. (1983). Coral Reefs of the Western Indian Ocean: A Threatened Heritage. Anbio., 12 (6), 349-353.

Smith, J.T. (1985). Water Resources in the Whitsunday Area. Water Research Foundation of Australia, North Queensland Regional Committee, James Cook University, Townsville.

Smith, S.V. (1984). Phosphorus Versus Nitrogen Limitation in the Marine Environment. Lim and Ocean. 29 (6), 1149-1160.

Smith, S.V., Kimmerer, W.J., Laws, E.A., Brock, R.E., Walsh, T.W. (1981). Kaneohe Bay Sewage Diversion Experiment: Perspectives on Ecosystem Responses to Nutritional Perturbation Pacific Science, 35 (4), 279-380.

Tomascik, T. and Sander, F. (1985). Effects of Eutrophication on Reef Building Corals: Growth Rate of the Reef Building Coral Montastrea Annularis. Mar. Biol., 87, 143-155.

Water Quality Criteria (1972). A Report of the Committee on Water Quality Criteria, National Academy of Sciences, Washington, D.C.

Wolonski, E., Jones, M. and Williams, W.T. (1981). Physical Properties of Great Barrier Reef Lagoon Water near Townsville . II Seasonal Variations. Aust. J. Mar. Freshwat. Res., 32, 321-324.