The current level of scientific understanding on impacts of terrestrial run-off on the Great Barrier Reef World Heritage Area

Statement prepared for the Reef Protection Taskforce by

Christian H. Roth (CSIRO Land and Water), David McB. Williams (Reef CRC / AIMS), Peter Ridd (James Cook University) and George E. Rayment (Sugar CRC / NR&M)

Provision of a credible and a comprehensive science base that reflects the general state of knowledge accepted by the scientific community and that is accepted by all members of the Reef Protection Taskforce is a critical prerequisite for the successful achievement of the Taskforce's objectives. This statement intends to provide a consolidated view of our current understanding of the impacts of terrestrial run-off on the Great Barrier Reef World Heritage Area (GBRWHA). In doing so, the statement seeks to allay concerns that there are conflicting views in the scientific community not being adequately reflected in the mainstream scientific debate on issues related to the link between land use impacts and the health of the GBRWHA.

The current level of generally accepted scientific understanding with respect to the above issues has been documented in detail in the recent review undertaken by David Williams on behalf of the Reef CRC. It represents the outcome of a review of existing published scientific literature, complemented by a robust and broad consultation of experts in the fields of marine and terrestrial sciences and whose expertise is relevant to the GBRWHA. The review document, which has been endorsed by GBRMPA and which is publicly accessible at www.reef.crc.org.au/aboutreef/coastal/waterqualityreview.shtml, has been made available to the members of the Reef Protection Taskforce. Its executive summary is also attached to this document for reference.

The executive summary clearly outlines what we currently know and what we don't know. A key message is that a significant proportion of the GBRWHA (including the outer reef) is not likely to be threatened by terrestrial runoff. Areas at risk are near-shore reefs and seagrass beds south of Port Douglas and within 20km of the coast. The areas of most concern are those between Port Douglas and Hinchinbrook as well as Bowen to Mackay. The other key conclusion is that we are still confronted with a high level of uncertainty concerning our understanding of processes and how these might relate to health of the GBRWHA. This is not surprising given the complexity of the often non-linear relationships of the ecological processes involved. Since compilation of the review, more scientific publications have become available or are in the process of being published, indicating that our state of knowledge is in constant flux and as new and sometimes contrasting views are introduced, healthy scientific debate is stimulated. This is normal and rigorous scientific debate is an essential part of the process of transforming scientific ***information*** into knowledge or ***understanding***.

For instance, very recent work published or being in the process of being published by P. Larcombe, P. Ridd and others (JCU) and not yet included in the review provides additional support to the view that increased sediment loads from runoff probably play a negligible role in turbidity or 'smothering' related impacts on near-shore ecosystems of the GBRWHA. Conversely, there is also new scientific evidence (K. Fabricius et al., AIMS) that the complex interactions between terrestrial sediment and the nutrients and organic matter associated with that sediment are leading to changes in the quality of the sediment, in turn possibly affecting deposition dynamics, so that in localised conditions, additional sediments originating from runoff may impact some near-shore ecosystems after all. This example illustrates the difficulty the scientific community faces in delivering consistent messages to concerned stakeholders and agencies. The consolidation of new information into knowledge takes time, and there is significant risk in drawing premature conclusions.

In summary, the assessment of the potentially adverse impacts of terrestrial runoff and delivery of pollutants (sediments and associated nutrients, pesticides, heavy metals) to the GBRWHA from land-based activities is not straightforward and will continue to be so for a while. The main reasons for this are:

- We have little or no baseline data to indicate what the GBRWHA looked like before European settlement. Much of our understanding has only emerged over the past decade or two, so that in many instances we have to infer from other reef systems with longer records and from the interpretation of "records" embodied within coral cores.

- Against the backdrop of strong disturbance from natural processes (cyclones, inherent climatic variability, wave re-suspension of sediments etc.) it is very difficult to distinguish or even quantify the relative contribution of anthropogenic disturbances. It is likely that adverse impacts will express themselves in reduced capability to recover from natural disturbances rather than becoming visible in the form of direct impacts.

- We are dealing with complex ecological processes, where inherent ecosystem buffering capacity makes it difficult to identify clear trends in change from relatively short-term studies. However, in many ecosystems, apparent resistance to change due to high buffering capacities can be followed by an abrupt ecosystem collapse once critical disturbance thresholds have been overstepped. Predicting these thresholds is extremely difficult, yet absolutely critical, as an overstepping can often lead to irreversible changes or to very slow rates of recovery when the "pressure" abates.

All three reasons are important enough to adhere to the precautionary principle in managing the land-based sources of impacts on the GBRWHA until we achieve more certainty in our understanding of impacts. However, the last of the three points raised above is the most compelling one to do this; whilst there is currently little evidence for widespread deterioration of near-shore systems (localised impacts have been documented), we might be closer to some of the thresholds than our current records allow us to determine. The very real risk is that by not undertaking any significant action now to reduce delivery of elevated levels of nutrients and pollutants to the GBRWHA, we may overstep some thresholds leading to irreversible loss of near-shore reef systems and sea grass beds. Moreover, whilst it is not within the scope of the Reef Protection Taskforce, it is worth noting that post-European land use has very significantly altered and in many cases caused significant damage to rivers or loss of wetlands in the majority of the catchment area of the GBRWHA. The direct and indirect impacts of the changes to or loss of freshwater biodiversity and food chain links to the GBRWHA have yet to be fully assessed.

In conclusion, we state that:

i. on the basis of the evidence available that post-European land use has significantly increased runoff and sediment associated nutrient and contaminant delivery to near-shore regions of the GBRHWA,
ii. in view of the detrimental impact this has had on freshwater aquatic systems,
iii. and given the significant risk that this impact may in future adversely affect areas of high exposure along the wet tropical and central Queensland coasts of the GBRWHA beyond those incidences of deterioration already documented,

there is a continued urgency for the Reef Protection Taskforce to proceed as planned and work towards a plan that will lead to a reduction of these impacts and risks.

Attachment:

Executive summary extracted from the review on 'Impacts of terrestrial runoff on the Great Barrier Reef World Heritage Area", prepared by D. McB. Williams for the Reef CRC (www.reef.crc.org.au/aboutreef/coastal/waterqualityreview.shtml)

Executive Summary

A Precautionary Note

There is currently significant cause for concern for the impacts of terrestrial run-off on nearshore coral reefs, seagrasses (see below) and estuaries and rivers (not covered here) in the Great Barrier Reef World Heritage Area. These impacts are a result of both past and present land use practices. This review focuses on what's happening outside the river mouths rather than trends in land use. It is important to understand, however, that while some significant improvements have been made in sustainable land use (eg the introduction of trash blanketing in some canelands and some increased attention to reducing sediment runoff in grazing lands), other factors negatively impacting on the World Heritage Area such as continued expansion of farming into marginal areas, continued increases in fertilizer application and loss of riparian vegetation and wetlands, continue to threaten to make the situation worse. If stronger action is not taken to further reduce runoff of sediment, nutrients and biocides, the present threat to these habitats will worsen. A precautionary approach to the management of nearshore areas is recommended given the relative lack of studies and the history of impacts of terrestrial runoff on coral reefs elsewhere

A Supply of Pollutants

A1 Flood Plumes

Most pollutants from the land are delivered to the GBRWHA during major flood events. Episodic high inputs of particulate and dissolved matter during flood events are an important and natural part of the ecology of the Great Barrier Reef and the associated continental shelf and estuarine environments. Discharge from both wet (eg Wet Tropics) and dry (Fitzroy and Burdekin) river catchments is dominated by large flood events associated with tropical cyclones and monsoonal rainfall. These flood events significantly raise nutrient and sediment loads in the rivers – particularly during the first major flood following the dry season.

Flood plumes are generally constrained close to the coast by prevailing south-east winds, the buoyancy of the plumes and Coriolis effects (effects of the earth's rotation). While some inshore reefs regularly experience floodwaters, most mid-shelf reefs see plumes less frequently than every ten years. Under unusually calm conditions, plumes can travel as far as some outer shelf reefs but their duration offshore is short.

Concentrations of contaminants in rivers during floods give some idea of relative concentrations in a plume close to the river mouth and immediately adjacent habitats, such as seagrasses, but these concentrations rapidly change in time and as the plume moves. This is a result of rapid consumption of dissolved nutrients by phytoplankton and subsequent changes in the plankton communities and the dynamics of contaminants and sediment particles.

A2 Sediments

Estimates of increases in sediment yield into the Great Barrier Reef Lagoon since European settlement (based on models of catchment erosion) are highly variable from catchment to catchment but range from about 1.6 to 4.1 based on models of sediment erosion. The most recent estimates (July 2001) of change in run-off of sediments from the land since 1800 is a 3 to 4-fold increase. Many biologically active and toxic trace elements associated with agrochemical products are attached to sediments. Most of this sediment is deposited close to the coast, particularly in the northward facing bays such as Bowling Green Bay, Cleveland Bay and Princess Charlotte Bay.

It is believed that increased sediment supply to the Great Barrier Reef will not increase sediment accumulation or turbidity at most coral reefs, because these factors are not currently limited by sediment supply. Turbidity in nearshore areas is primarily caused by wind-driven re-suspension of bottom sediment. Most of this sediment is not recent but has accumulated over the last five or six thousand years as the sea has inundated the continental shelf and risen to its current level.

A3 Nutrients

Most of the nutrients (nitrogen, N and phosphorus, P) required by the pelagic and reef communities of the Central GBR are derived from recycled biological material. External sources of nutrients come from rivers, rainfall, upwelling from the Coral Sea and from nitrogen fixation of atmospheric N by the blue-green alga, *Trichodesmium*. Terrestrial run-off, estimated at $70km^3$ of water per year, is the largest external source of nutrients to the GBRWHA. The most recent estimate of increases in run-off of phosphorous and nitrogen from the land to the GBRWHA compared to pre-1800 levels is a 6 to 10-fold increase in phosphorous and a 2-fold increase in nitrogen. The extent to which this nutrient run-off has increased the total amount of nutrients to the marine environment, and the nearshore zone in particular, is uncertain.

The growth of phytoplankton and seagrasses in GBR waters appears to generally be constrained by the availability of nitrogen, rather than by phosphorus or silicate. The nitrogen most immediately available to plants and animals is dissolved inorganic nitrogen (DIN), primarily ammonia and nitrate. Land use increases the available DIN to the GBR.

In nearshore waters <20m deep, the area most impacted by terrestrial run-off, wind-generated wave action re-suspends bottom sediment, releasing nutrients. The cycling of nutrients between water column and the benthos and from particulate to dissolved forms in general is not well understood in GBR waters and is critical to understanding the impact of runoff from the land on the GBR.

B Potential Impacts

Because of the behaviour of flood plumes and the maximum depth of sediment re-suspension by non-cyclonic waves, any adverse effects of land-based inputs on the GBRWHA are likely to be restricted to nearshore areas – broadly within 20km of the coast and in waters less than 20m deep.

B1 Sediments (Coral Reefs, Seagrasses)

Thriving coral reefs with high coral cover, and in some cases high diversity, do occur in episodically turbid nearshore waters of the GBR. Deposition of sediments near river mouths may, however, threaten seagrasses and there are anecdotal but unconfirmed accounts of coastal coral reefs in the Wet Tropics being buried by sediment. It's not clear whether this happened to thriving reefs or reefs where corals had already died as a result of other causes.

Significant increases in sedimentation on nearshore coral reefs would be likely to cause changes in community structure and create less favourable habitats for hard corals, zooxanthellate soft corals and calcareous coralline algae. The latter are critical in reef building. Loss of reef structure filled in by sediment may lead to a reduction in numbers of herbivorous fish and a subsequent increase in macroalgae.

B2 Nutrients (Coral Reefs, Seagrasses)

For many years the greatest concern regarding increased levels of nutrients on coral reefs has been that at a certain threshold level of nutrients, increased growth of macroalgae will occur and corals will be overgrown. More recently, studies have challenged both the concept of a simple threshold level of nutrients and the concept that increasing nutrient levels will inevitably lead to increased growth of macroalgae. Many studies demonstrate that herbivores readily consume increases in algae and that the primary cause for coral reefs shifting to algal-dominated reefs is likely to be declines in herbivore numbers through disease (eg sea urchins in the Caribbean) or chronic over- fishing. The major herbivorous fishes on the Great Barrier Reef are not targeted by fishermen and are rarely caught.

Experimental studies exposing corals to artificially high levels of nutrients have demonstrated direct effects on corals including changes in coral growth and calcification, disruption of reproduction (embryo development, fertilization rates) and changes in settlement success of planulae.

It has been suggested that a primary cause of crown-of-thorns outbreaks may be heavy terrestrial run-off increasing nutrient inputs into reef waters – the "terrestrial run-off hypothesis". This could be a result of natural run-off or it could be exacerbated by changes in land use. Evidence for a linkage between extreme rainfall events and the last three outbreaks of crown-of-thorns starfish on the Great Barrier Reef has recently increased. A relationship between outbreaks and changes in land use has neither been demonstrated nor disproven.

C Status of GBRWHA Habitats (including Observed Impacts)

C1 Difficulties of Detecting Impacts

Difficulties in making definitive statements of impacts of terrestrial runoff on GBRWHA habitats include: acute and relatively frequent natural disturbance of these habitats; the relatively short duration of monitoring programs (20 years or less); the lack of unambiguous pristine controls for comparison because many of the major changes in land use occurred before monitoring of coastal and reef ecosystems was initiated; and a poor understanding of the capacity of the waters of the continental shelf to buffer and absorb cumulative changes - in particular the fate and fluxes of nutrients are poorly understood.

C2 Status of Coral Reefs

Based on limited research to date, clear impacts of enhanced runoff of sediments, nutrients and contaminants (as a result of land use) on coral reefs of the Great Barrier Reef ecosystem have proven difficult to detect. Impacts are unlikely for the majority of reefs that are located well offshore. There is, however, cause for concern of potential impacts on the coastal and island fringing reefs and nearshore patch reefs within 20 km of the shore in the Wet Tropics from Port Douglas south to Hinchinbrook and from the Whitsundays (Gloucester Island) south to Mackay. This area includes 209 reefs (approximately 28% of the total number of nearshore reefs of the GBR) covering 135 square kilometers (approximately 3% of total area of nearshore reefs in the GBR). They are a unique part of the ecosystem and include all the inshore reefs in the Cairns and Whitsunday regions.

This concern is primarily based on estimated increases in nutrient and sediment run-off from the land compared to pre-European times (varies among catchments), anecdotal community observations of changes in the nearshore reefs of the Wet Tropics (Hinchinbrook to Port Douglas) and observations of a mismatch between substantial past reef building capacity and non-existent or limited present reef-building capacity for two sites in the Whitsundays close to the mouths of the Proserpine and O'Connell Rivers.

On occasions nearshore reefs have been found to experience concentrations of nutrients and sediments that could give cause for concern (as indicated by field and laboratory experiments) and on other occasions flood plumes that are usually relatively ephemeral – lasting hours or days – have also persisted for up to three weeks after initial flooding at large distances away from the river mouth. There is very little information, however, on the doses – how much for how long – the reefs actually see during a flood plume. This is a critical area for further research on the impacts of terrestrial runoff on coral reefs of the GBRWHA.

Significant impacts of land use on nearshore reefs could potentially go undetected for a considerable time. Healthy coral reefs have evolved to recover from acute natural disturbances such as cyclones, floods, and crown-of-thorns outbreaks. The consequences and recovery from these events can be readily observed by the amount and diversity of corals and fishes, for example. It is these aspects of reefs that are most readily monitored. Effects of chronic impacts such as human-induced increases in nutrients and sediments on nearshore reefs are going to be much more difficult to observe. They would occur gradually over time and would not be as dramatic as the effects of cyclones or crown-of-thorns outbreaks. A gradual shift in the community structure of affected reefs may occur due to differences in the ability of species to cope with a changing environment. Such changes may have occurred prior to the start of existing monitoring programs. Experiments are also suggesting that any effects on adult corals are at first likely to be sub-lethal, such as decreased reproductive success or survival of recruits, and these are not readily observed. One of the greatest concerns is that these gradual, unseen impacts may only be detected when coral reefs fail to recover from acute natural disturbances.

C3 Status of Seagrasses

Major seagrass beds occur in coastal areas particularly vulnerable to runoff. Major potential anthropogenic threats include reduction in the light available for photosynthesis, burial by sediment and a reduction in function caused by herbicide runoff in areas adjacent to catchments with intense cropping. The major subtidal seagrasses in the Great Barrier Reef region are low biomass species that are relatively tolerant to low light levels in the water column. Many intertidal and subtidal species are naturally ephemeral and regenerate from seed banks provided these are not damaged by extreme weather events. The levels of nitrogen and phosphorus in some species of intertidal seagrasses in the Central Section of the Great Barrier reef are highly variable. The significance of this variation is unknown.

There is circumstantial evidence that the impacts of extreme weather events such as floods and cyclones on seagrass habitats can be influenced by land use. For example, anecdotal evidence suggests that the loss of seagrass from Hervey Bay following the 1992 floods was unprecedented in the last 100 years, even though the magnitude of the flood was not. It was concluded that the impacts of natural disturbance on seagrass bed can be exacerbated by poor catchment management and the resultant increase in sediments and nutrients entering coastal waters. This increase may affect the ability of seagrass beds to recover from damage caused by natural events.

Data are not available to indicate the extent of change in seagrass habitats off the east coast of Queensland over an extended time-frame (decades). The natural variability of the Great Barrier Reef seagrasses contributes the uncertainty of their status. However, work done in Moreton Bay to the south of the Great Barrier Reef region suggests that this it is likely that changes in water quality have reduced the depth range and hence areal extent of at least some species of subtidal seagrasses in the region. Evidence for major declines in the numbers of dugong (which feed specifically on seagrass) along the Queensland coast south of Cooktown in recent decades has given rise to speculation that changes in the distribution and community composition of the seagrass habitats may be a contributing cause.

C4 Status of GBR Shelf Waters

Assessment of the status of GBR shelf waters is complicated by the large natural spatial and temporal variability in nutrients and the pelagic communities (unlike most reef systems studied elsewhere) and a lack of long-term records. Evidence of nutrient enrichment of the GBR lagoon has been suggested based on historical studies at Low Isles and comparisons of nutrient levels in the GBR lagoon with coral reefs waters elsewhere. However, more extensive phytoplankton studies have found biomass and composition consistent with an unimpacted system and failed to find evidence of large-scale eutrophication.

A large-scale monitoring program of chlorophyll *a* (a surrogate for nutrient concentrations) begun in 1992 has found the highest mean average concentrations of chlorophyll *a* in the inner section (within 20km of the coast) between Townsville and Port Douglas, including the Wet Tropics area of greatest concern in terms of potential impacts. This probably results from the extensive river run-off in this region. It is not clear whether these concentrations have been enhanced as a result of recent changes in land use. It is also not yet clear whether or not concentrations of chlorophyll *a* have increased over the monitoring period.

C5 Impacts of Pollutants other than Sediments and Nutrients

Pollutants impinging on the GBRWHA (other than unnaturally high levels of nutrients and sediment) include insecticides and herbicides, heavy metals and polyaromatic hydrocarbons. Studies to date have generally found low concentrations of these pollutants, indicative of a relatively unpolluted environment. Exceptions are coastal sites adjacent to human activity such as ports and harbours, urban centers and areas adjacent to intensive agricultural activity. Elevated pollution concentrations are generally the consequence of effluent discharge, urban stormwater and agricultural and industrial runoff. There is concern, however, that much of the data on pollutants in the GBRWHA are dated and a call has been made for an update of information on the distribution and impact of potential pollutants. Just as attention is turning to monitoring of non-lethal effects of nutrients and sediments on reef communities, so attention should be given to more sophisticated and sensitive indicators for monitoring impacts of other pollutants.

The pollutant of greatest current concern for potential impacts on the GBR, in addition to dissolved inorganic nitrogen, is the herbicide diuron. Significant levels of diuron, used extensively in cropping, have been found in the sediments adjacent to all rivers examined in the high rainfall (Wet Tropics) coast between Port Douglas and Townsville and the Fitzroy River. Diuron has also been detected in inter-tidal seagrasses between Cairns and Townsville and is a potential threat to seagrasses.