Most pollutants from the land are delivered to the Great Barrier Reef Heritage Area during floods caused by passing tropical cyclones and monsoonal rainfall. As the rivers reach the coast, billowing flood plumes with elevated sediment and nutrient loads appear. Approximately 200 near-shore reefs are under pressure due to regular exposure to flood plumes.

Do sediments sully the reef?

Steve Davidson investigates the effects of cattle and cane on the corals of the Great Barrier Reef.

A diver surveys a healthy inshore reef.

The Great Barrier Reef World Heritage Area collects the run-off waters from a quarter of the State of Queensland, a vast catchment covering 400 000 square kilometres of mostly agricultural land.

Some 70 billion cubic metres of water drains from the catchment each year, delivering on average 10–15 million tonnes of sediment, 43 000 tonnes of nitrogen and 7000 tonnes of phosphorus to the heritage area.

The annual natural sediment yield from the catchment is estimated to have risen from 1–5 million tonnes to 15 million tonnes since 1850, according to a report for federal and state governments prepared by the Reef Science Panel, chaired by Queensland chief scientist, Dr Joe Baker.

The report, which will underpin the development of a reef water quality protection plan, noted that annual nitrogen exports had increased at least two-fold and phosphorus at least three-fold in the same period. The contribution of the various land uses in the catchment to these sediment and nutrient loads, however, and the likely impacts on coral reefs and other marine ecosystems, remains contentious.

Altered landscapes

The primary cause of erosion and nutrient loss in the GBR catchment is the removal of vegetation. About half the catchment has been cleared to some extent for grazing, farming and mining since 1850.

Another factor is fertiliser and pesticide use. Both the area of sugarcane cultivation and fertiliser and pesticide use have risen steadily. Less than half the nitrogenous fertiliser added to sugarcane is taken up by the crop. Much of the remainder ends up in waterways, along with excess phosphorus bound to suspended sediments.

Pesticides, such as the herbicide diuron, and toxic trace elements such as mercury and cadmium from agrochemical products, also attach to sediments.

Great Barrier Reef Marine Park Authority

When corals are experimentally exposed to high levels of nutrients, direct effects have included reduced settlement success (coral larvae need to find a place to live), disruption of reproduction and changes in coral growth and calcification.

Diuron has been detected in inter-tidal seagrasses and is a potential threat to these habitats. It has been speculated that the dramatic decline in dugong, which feed on seagrass, may be partly due to changes brought about by lower water quality.

Cattle-grazing is the dominant land-use in the reef catchment, involving some 75% of the landscape, with lesser areas of forestry, sugarcane and horticultural crops. Rainforests mostly occur towards the northern end of the catchment. About a million people live in the area.

Due to the vast areas involved in pastoralism, most of the collective sediments and nutrients reaching the coast come from cattle grazing lands in the drier catchments of the Burdekin and Fitzroy rivers.

But the Reef Science Panel report cites evidence from several river catchments that nitrate concentrations rise sharply as rivers enter areas of intensive sugarcane production.

For example, in the Johnstone River catchment, sugarcane occupies just 12% of the land, yet contributes close to half the nitrate exported. In contrast, rainforest covers more than half the Johnstone catchment, yet contributes only about 10% of the nitrate load. Cane farming also contributes a disproportionate percentage of the total phosphorus transported from the catchment to the sea.

Dr Rob Bramley and Dr Christian Roth of CSIRO Land and Water found a similar picture in the mighty Herbert River catchment. They found that, compared with grazing and forestry, sugarcane production had a significantly greater impact on water quality in terms of concentrations of nitrogen, phosphorus and total suspended solids.

Crops certainly generate plenty of sediment in rivers. The Reef Science Panel report indicates four-fold, 15-fold and four-fold sediment increases for rangelands, cropping lands and urban areas respectively, since 1850, indicating the marked impact of cropping. These are probably conservative values.

Flood plumes

In an overview of run-off impacts, Dr David Williams of CRC Reef says that most pollutants from the land are delivered to the GBR Heritage Area during floods caused by passing tropical cyclones and monsoonal rainfall.

As the rivers reach the coast, billowing flood plumes with elevated sediment and nutrient loads appear. Fortunately, these plumes tend to hug the coast due to the prevailing south-easterly winds, the buoyancy of the less-salty plumes, and Coriolis effects caused by the Earth's rotation.

This means that although some 200 near-shore reefs are under pressure due to regular exposure to flood plumes, most reefs, being more than 20 kilometres offshore, experience run-off only occasionally and briefly, when conditions are unusually calm.

Another saving grace for outer reefs is the biological action of phytoplankton (free-floating, microscopic organisms) that rapidly consume dissolved nutrients such as nitrogen and phosphorus. But resulting phytoplankton blooms could, in turn, have unpredictable consequences.

So although sediment discharge to the GBR lagoon is estimated to be several times greater than in 1880, most of the sediments in the flood plumes are deposited close to the coast in northward facing bays, rather than on outer reefs. This existing pool of coastal sediments has been deposited there over thousands of years.

A computer modelling study by Dr Brian King of Asia-Pacific Applied Science Associates, and colleagues, indicates that the typical one-in-15-year Burdekin River flood plume stretches 400 km north to Cairns.

During these events, it combines with the discharges of several rivers draining the wet tropics, exposing many mid-shelf reefs to low-salinity waters.

Furthermore, this infrequent flood plume probably extends to the outer reefs north of Townsville, all the way to Cape Melville. The plume might carry dissolved particles that far, but sediments tend to be deposited closer to river mouths.

Impacts on the reef

Measuring the impact of run-off on the reef is no easy task and this creates a real dilemma.

Overseas experience in Hawaii and Florida tells us that by the time the links between run-off and coral death are scientifically established, it is almost too late. By then, the coral reef in question is severely degraded and is unlikely to recover for many years, and not without significant changes to land-use practices.

Already, says the Reef Science Panel, some areas of the GBR most affected by river run-off appear to be degraded or slow to recover from natural events such as cyclones. This is cause for concern as experience elsewhere tells us that the first major sign of run-off impact tends to come when coral reefs lose their inherent ability to recover from other disturbances, such as cyclones or infestation with crown-of thorns starfish.

Worldwide, many studies have shown that enhanced turbidity, sedimentation or nutrient availability lead to local losses of reef biodiversity, reduced or failed coral

Land clearing is the primary cause of erosion and nutrient loss in the Great Barrier Reef catchment. About half the catchment has been cleared since 1850.

Great Barrier Reef Marine Park Authority

Most of the collective sediments and nutrients reaching the coast come from cattle grazing lands in the drier catchments of the Burdekin and Fitzroy rivers.

recruitment, greater mortality of juvenile corals and displacement of the dominant hard corals, which build the reef framework, by algae.

Some corals are thought to cope with short-term or low-level exposure to run-off, but how they deal with chronic low-level doses of sediments and nutrients is less understood. Some corals can actively remove sediments using tentacles, cilia, mucous or tissue expansion, but this requires additional expenditure of energy by polyps.

In one experiment, exposure to sedimentation caused changes in the photosynthetic performance of a common inshore coral of the GBR. Colonies of *Montipora peltiformis* recovered from short-term or low-level sedimentation within 36 hours, but longer exposure or high levels of sedimentation killed exposed colony parts.

The circumstantial evidence for deleterious effects of run-off also continues to grow. Studies on 144 reefs of the GBR showed that abundance of beneficial crustose coralline algae, critical to reef building, was relatively high on reefs with low sedimentation. On the inner third of the shelf, the most sediment exposed reefs were unsuitable habitats for the coral-like algae.

Similarly, surveys of 161 reefs off Queensland indicated that the biodiversity of soft corals was low in areas of high turbidity and at inshore areas from 17–20° South.

A study by Dr Katharina Fabricius of the Australian Institute of Marine Science compared marine communities on near-

Reef-aware agriculture

COMMUNITIES can take practical steps to reduce sediment, nutrient and pollutants contained in run-off waters.

Voluntary approaches include integrated catchment management and industry codes of best practice.

The sugar industry has developed the COMPASS program, which allows growers to assess the economic and environmental sustainability of their farms through a workshop and workbook.

Cattle producers are being encouraged to embrace sustainable grazing practices such as lower stocking rates combined with rotational wet-season spelling, to limit livestock access to riverbanks and to replant and retain native vegetation, especially along watercourses.

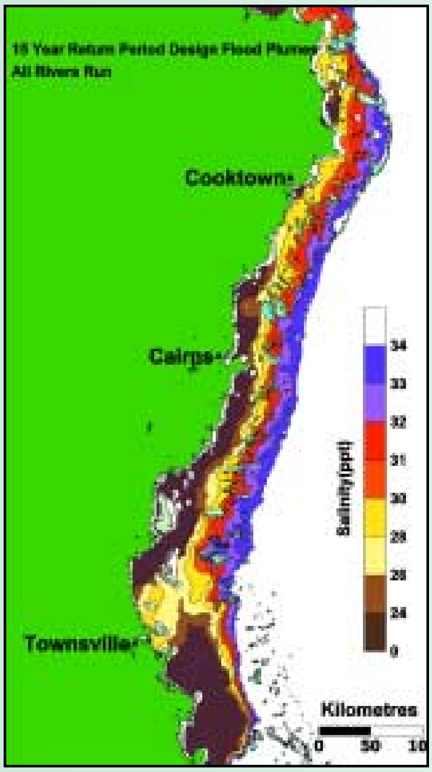
Dr Andrew Ash and colleagues at CSIRO Sustainable Ecosystems and the Department of Primary Industries have developed guidelines for sustainable grazing management through the ECOGRAZE program.

Dr Christian Roth of CSIRO Land and Water, and several colleagues, have recommended practical steps to make sugarcane production more environmentally sound in the Lower Herbert River catchment. Many of these steps are applicable to other sugar growing regions.

Recommendations to curb the export of sediment from farms include:

- early planting of cane to allow time for soil consolidation and canopy closure;
- retaining plant cover before early wet season thunderstorms that wash sediments away;
- phasing out water furrows, which are an important source of sediments;
- less frequent grading of farm drains; and
- the use of shallow spoon drains (rather than steep-walled drains) with good grass cover to act as sediment traps.

Water quality will also be improved by wider adoption of management options such as trash blanket harvesting (retention of cane trash on fields after harvest), fallow crops rather than bare soil, minimum tillage, avoiding excessive fertiliser and incorporation of fertilisers into the soil to avoid direct run-off of surface-applied nutrients.



Above: Typical one-in-15-year flood plumes expose many mid-shelf reefs to low-salinity waters. (Normal seawater salinity is 35 ppt.) Most of the sediments in the flood plumes are deposited close to the coast in northward facing bays, rather than on outer reefs.

Above left: Degraded inshore reefs have less coral and more algae than pristine areas.

Left: A thriving coral reef epitomises the concept of biodiversity.

shore island reefs adjoining the wet tropics with reef communities further north, off Cape York Peninsula.

While the wet tropics reefs are exposed to near-annual river plumes from catchments supporting sugarcane crops, horticulture and grazing, the northern ones adjoined areas of negligible clearing of native vegetation and little agriculture apart from some cattle grazing.

Fabricius found that overall the northern reefs, adjacent to more pristine catchments, had higher levels of coral cover, greater coral biodiversity, better recruitment of larval corals and greater survival of juvenile corals.

When corals are experimentally exposed to high levels of nutrients, direct effects have included reduced settlement success (coral larvae need to find a place to live), disruption of reproduction and changes in coral growth and calcification.

The hypothesis that the main cause of crown-of-thorns starfish outbreaks is increased nutrients in reef waters due to run-off has been somewhat strengthened by evidence of a linkage between the last three starfish outbreaks and extreme rainfall events. But the jury is still out on the link between starfish population explosions and changes in land use.

Sceptics might argue that all the evidence for negative impacts of modern day run-off on reefs is inconclusive. After all, there is little historical information on the status of river water quality and the GBR at the time that Captain Cook sailed through the maze of reefs and islands.

The issue remains somewhat controversial. However, work reported in the journal *Nature* in 2003 demonstrates that coral itself may hold the answer to pre-European versus modern rates of sedimentation (see story at right).

Managing catchments for corals

Reef scientists say that uncertainty about impacts does not justify a gung-ho approach to land-use management in the GBR catchment.

The need for more scientific inquiry and the disturbing history of run-off impacts on coral reefs elsewhere in the world point to the need for a precautionary approach to land and reef management in Australia. The fact that any terrestrial run-off effects on corals, such as reduced reproductive success, are at first likely to be sub-lethal and therefore insidious also flags a need for caution.

Williams highlights the fact that while important improvements have been instigated in sustainable land use, notably the introduction of trash blanketing in some cane lands and more attention to reducing sediment loss in grazing lands, there is also bad news.

Farming continues to expand into marginal areas, application of fertilisers is increasing and wetlands and surrounding vegetation continue to disappear.

Reef experts are concerned and pushing for action. The Reef Science Panel concluded that the measures it recommended to improve the quality of water entering the GBR were 'fully justified on the scientific evidence to hand'.

The Rainforest and Reef cooperative research centres have been granted $2.25 million of joint funding from the federal government to identify, monitor and minimise water quality problems associated with agriculture so as to safeguard the GBR.

The three-year research project has been dubbed the Catchment-to-Reef collaboration and it should help to bring about a compatible co-existence of cattle, cane and coral in years to come.

More about run-off and the GBR

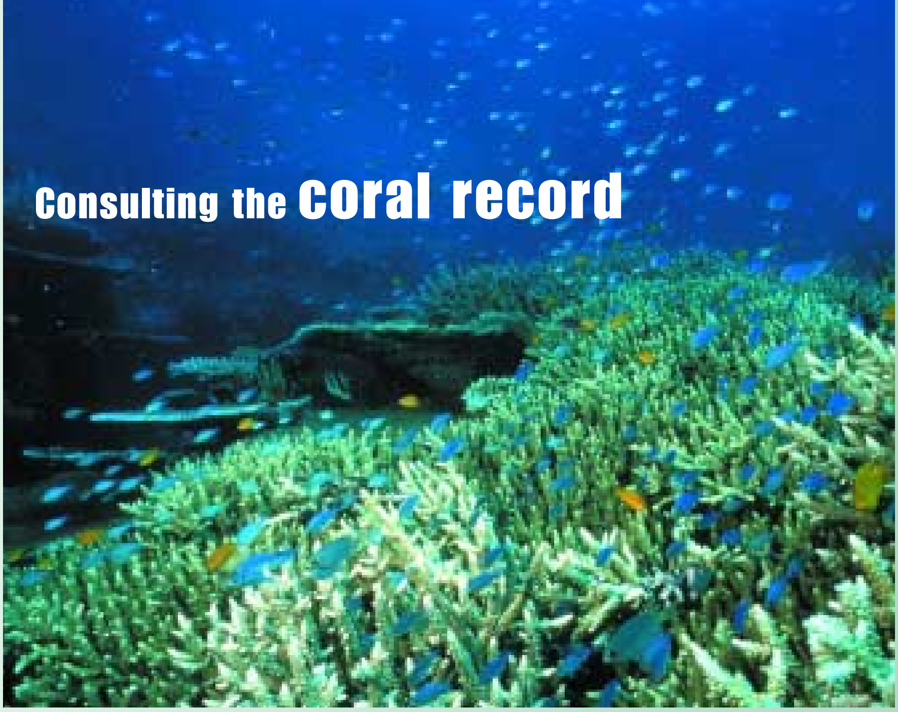
CRC Reef Brochure, *Land Use and the Great Barrier Reef World Heritage Area*. www.reef.crc.org.au/publications/brochures/index.html

Report of the Reef Science Panel, A Report on the Study of Land-sourced Pollutants and their Impact on Water Quality in and Adjacent to the Great Barrier Reef. www.premiers.qld.gov.au/about/reefwater.pdf

Review of Impacts of Terrestrial Run-off on the Great Barrier Reef World Heritage Area. www.reef.crc.org.au/aboutreef/coastal/waterqualityreview.html

Abstract: About one-quarter of the Queensland land surface drains into the Great Barrier Reef World Heritage Area. Run-off of sediment, nutrients and other pollutants has increased several-fold since before European settlement, but the issue of impact on the reef has been contentious. Most of the sediment and nutrients come from the cattle grazing lands in the drier catchments of the Burdekin and Fitzroy rivers due to their vast size. Sugarcane production involves much less land, but makes a disproportionate contribution to sediment, nitrogen and phosphorus discharge. Flood plumes tend to hug the coast and the greatest pressure due to run-off seems to be on some 200 near-shore reefs. Evidence for deleterious impacts on coral reefs is growing while overseas experience indicates that the first sign may be inability of reefs to recover from natural disturbance. Reef scientists urge a precautionary approach and sustainable land use practices to improve water quality.
Keywords: Great Barrier Reef, sediments, nutrient loads, run-off, water quality, sugercane farming, cattle farming.

Consulting the coral record


Great Barrier Reef Marine Park Authority

SCIENTISTS are consulting the wisdom of long-lived corals for evidence of sediment discharge from Queensland rivers before and after European settlement.

Professor Malcolm McCulloch and his colleagues at the Australian National University, working with the Australian Institute of Marine Science, have accessed this coral record by analysing cores taken from massive 300 to 400-year-old *Porites* corals of the inner Great Barrier Reef.

They drilled cores up to 5.3 metres long from corals at Havannah and Pandora reefs, which experience episodic discharges of freshwater flood plumes from the Burdekin River, and analysed them using a new sophisticated type of mass spectrometry.

Not only do the corals keep a record of flood events, manifested as narrow fluorescent or luminescent bands in the coral skeleton, they also contain various amounts of the element barium, which indicates how much sediment was present in river run-off during the lifetime of the coral.

When river sediment reaches coastal seawater, the barium in suspended clay particles is released, acting as a tracer.

The amount of barium released is proportional to the amount of sediment and the amount of barium subsequently incorporated into the carbonate skeleton of corals is directly proportional to its concentration in surrounding seawater.

So barium content provides a long-term record of changes in sediment loads in river discharge, with a resolution close to weekly.

The longest coral core, analysed for the period 1750–1985, reveals an interesting pattern of sediment supply.

Before European settlement near the Burdekin in 1862, surprisingly little sediment was associated with flood plumes. From the early 1800s to 1860, which included major floods in the years 1811, 1817, 1819 and 1831, the coral shows no barium peaks despite major luminescent bands indicating flood events.

Soon after European settlement, however, the behaviour of barium changed dramatically.

The first major flood following European settlement, in 1870, coincided with a strong barium peak, indicating a significant increase in sediments delivered to the inner reef.

This pattern of more frequent and more intense sediment discharge has continued ever since, leading the researchers to conclude that sediment delivery from the Burdekin has increased by 5–10 times since European settlement.

The change has not been gradual. McCulloch and his colleagues say that within a decade or two of the arrival of European settlers in northern Queensland there were already massive increases in river sediment loads.

They attribute this to the rapid expansion in numbers, firstly of sheep, and then cattle.

Back in 1862, there were no sheep or cattle in the Townsville region. By 1868 there were 176 956 sheep and 31 098 cattle and, by 1990, there were no sheep but more than a million cattle. These hoofed animals increase erosion in the catchment.

Coral readings also confirm that run-off events following drought, when protective plant ground cover is minimal, are especially high in sediments.

More about the coral record

McCulloch M Fallon S Wyndham T Hendy E Lough J and Barnes D (2003) Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. *Nature*, 421:727–730.