Water quality in sugar catchments of Queensland

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Abstract Water quality condition and trend are important indicators of the impact of land use on the environment, as degraded water quality causes unwelcome changes to ecosystem composition and health. These concerns extend to the sea, where discharges of nutrients, sediments and toxicants above natural levels are unwelcome, particularly when they drain to the Great Barrier Reef World Heritage Area and other coastal waters of Queensland. Sugarcane is grown in 26 major river catchments in Queensland, most in environmentally sensitive areas. This puts pressure on the Queensland Sugar Industry to manage the land in ways that have minimum adverse off-site impacts. Sugar researchers including CRC Sugar have been associated with water quality studies in North Queensland. These include investigations and reviews to assess the role of groundwater as a pathway for nitrate loss from canelands in the Herbert Catchment, to find causes of oxygen depletion in water (including irrigation runoff) from Ingham to Mackay, to use residues of superseded pesticides as indicators of sediment loss to the sea, and to assemble information on water quality pressure and status in sugar catchments. Key findings, plus information on input pressures are described in this paper, and areas of concern and opportunities discussed.

Keywords Dissolved oxygen; fertilisers; land use; nutrients; pesticides; reef; sugarcane; water quality

Introduction
The Rio Declaration on Environment and Development of June 1992 (Agenda 21) strengthened the resolve of nations, among other measures, to incorporate environmental protection as an integral part of the development process. The need to protect the oceans, seas and freshwater resources for present and future generations, and to conserve, protect and restore the health and integrity of the Earth’s ecosystems were recognised. At that time, there was increasing awareness that modified land use and agricultural practices had caused unwelcome changes to ecosystem composition and health. Symptoms included nutrient enriched waters, blooms of blue-green algae, loss of wetlands and riparian vegetation, increased salinity, the mobilisation of pathogens, and pesticide residues. These concerns extended to the sea, where land-based sources of nutrients, toxicants and sediments could impact adversely (e.g. Furnas et al., 1995). Importantly, the concerns have not abated, prompting the Commonwealth of Australia and the States to implement a National Action Plan for Salinity and Water Quality and the Queensland Government, its present Reef Protection Plan.

A related initiative in 1995 was to establish the Cooperative Research Centre for Sustainable Sugar Production (CRC Sugar), with programs and activities incorporating the three elements of sustainability, namely productivity enhancement, sustaining soil and water resources, and protecting the environment. While the focus was on the Australian Sugar Industry, most of Australia’s sugar cane is grown in tropical and sub-tropical Queensland (approximately 16° to 28° south of the Equator) on around 410,000 ha of relatively flat land, mostly on the flood plains of watersheds that drain to the South Pacific Ocean, inclusive of waters of the Great Barrier Reef World Heritage Area, the Great Sandy Region and Moreton Bay.

By that time, Moss and Bennett (1991) had concluded licensing and regulation had reasonably effectively controlled point sources of waterway pollution in northern Queensland.
However, there was growing concern that coastal primary production (cropping, grazing, timber) had imposed pressures on river water quality and the Great Barrier Reef from accelerated soil erosion, the draining of wetlands, removal of riparian vegetation, changes to water flows, and the use of fertilisers and pesticides. Systematic water quality condition and trend monitoring had commenced (e.g. Mitchell et al., 1991), but the extent to which sugarcane production was contributing to diffuse or non-point source water pollution was unclear, accepting that the term pollution refers to a deleterious change in the chemical, physical and/or biological qualities of components of an ecosystem due to human activity. The purpose of this paper is to position the sugar industry in Queensland’s water quality debate, using findings from CRC Sugar initiatives and the research of others. Opportunities to lessen pressures on water quality are raised and discussed.

**Land use “pressure”**
For the periods 1897, 1944–45, and 1983–84, there were progressive increases in total areas being cropped in coastal Queensland, mostly for sugarcane (Pringle, 1991). A trebling in the area under cane in Queensland occurred during the period 1951 to 1988 (Pulsford, 1991), with a further increase of over 40% in the last decade (CANEgrowers, 1999). This rapid rate of expansion (now suspended) was closely correlated to population growth in Queensland’s coastal zone (Figure 1).

Clearing for sugarcane cropping in the early 1990s was prominent in the Herbert, Murray, Haughton, and Plane Creek Catchments. For example, 18.5 km$^2$/yr of vegetation was lost in the Herbert between 1991 and 1995, adding to the 1.35 and 0.33 km$^2$/yr cleared for pasture and urban uses, whereas re-growth was only 0.54 km$^2$/yr. The low international price for sugar may see further land use change as marginal cane lands (from a productivity viewpoint) are forced by economics into other uses.

Nowadays, sugarcane is grown in 26 major river catchments in Queensland from the Daintree in the north to an aggregation of small catchments on the South Coast. Twenty-five of these drain to the east, the exception being the Walsh/Mitchell River that drains to the Gulf of Carpentaria from parts of the Atherton Tablelands. Only in seven catchments [Mossman (10.0), Mulgrave/Russell (13.1), Johnstone (14.8), Haughton (10.4), O’Connell (11.1), Pioneer (17.9), and Plane (21.0)] does sugarcane occupy $\geq$ 10% of the total catchment area. Sugar cane occupies < 5% of 15 of the remaining river catchments and < 0.3% of the Burdekin and Mitchell Catchments. More details are given in Figure 2.

Overall, sugarcane farming involves just over 1% of the total land area of all of Queensland’s coastal catchments. It follows that other land uses will have the dominant influence on river water quality, in-stream sediment loads, nutrient fluxes, and discharges to the sea, particularly during major run-off events (Rayment, 1999). On a unit area basis, however, cane lands make disproportionate contributions to in-stream loadings of labile forms of carbon and nutrients such as nitrate and phosphate (Hunter and Walton, 1997).

**Inputs and land to water movements**

**Sediments**
Unit suspended sediment yields based on measured data from the Barron River, Babinda Creek, Tully River, Herbert River, Burdekin River and headwaters of the Flinders River range from 29 to 94 t/km$^2$, with a strong influence of vegetation cover (lower when vegetation cover is high). Moreover, sediment yields of lands under cropping almost always increase by a factor of 10 or more, when compared to natural catchment yields (Rayment and Neil, 1996). Sediment increase factors for the Tully River and the Banyan Creek Sub-catchment were about 15 and 30 during cyclone Ivor (Neil and Yu, 1996).

Ignoring the remobilisation of in-stream sediments, soil erosion driven by irrigation and
rainfall events, and the collapse of stream-banks during periods of high stream flows, are the major sources of suspended sediments to streams (Rayment and Neil, 1996). For example, annual soil losses in row crop sugarcane in the Johnstone River Catchment have ranged from <50 to 500 t/ha [average of 150 t/ha (Prove et al., 1995)]. Near Mackay, where the rainfall is lower, measured annual soil losses ranged from 42 to 227 t/ha (Sallaway, 1979). These losses have now been lowered consistently to <5–15 t/ha/yr by moving cane assignments to erosion-resistant lands, the implementation of soil conservation plans, and by green cane trash blanketing (GCTB) (Hardman et al., 1985). Soil loss rates as low as 1–4 t/ha/yr are possible with GCTB and zero tillage. As the nutrient enrichment ratio of water-eroded soil generally decreases as sediment yield increases (Rose and Dalal, 1988), the lesser quantities of sediment in runoff from trash blanketed cane fields may be partly off-set by higher nutrient and heavy metal enrichment of cane soils.

Information on run-off susceptibility classes for bare and covered canelands is lacking in most areas but is available for soils of the Lower Herbert. The highest likelihood of run-off generation and hence the greatest threat of overland movement of particles and solutes to waterways is expected to the north of the Herbert River in the Ripple Creek Sub-catchment and in lower parts of the Stone River Catchment. Well drained levy soils of the Herbert River have low run-off incidence, off-set by enhanced leaching of solutes (Bohl and Roth, 1999). Caution is needed, however, as gully erosion can be an important pathway for accelerated movement of particles to streams (Donnelly et al., 1996).

With intensification of water quality monitoring, particularly in coastal rivers of north Queensland, useful estimates of sediment (and nutrient) fluxes are emerging, mostly at sub-catchment and catchment scales. These confirm the importance of major rainfall/runoff events. For example, in a single four-day event associated with Cyclone Sadie, the South Johnstone River at South Johnstone transported 67,000 tonnes of suspended sediment (Hunter, 1996). Most estimates of sediment flux, however, have come from modelling. An example for suspended sediments, derived from Moss et al. (1993), is given in Figure 3. Here, sugar is estimated to contribute around 9% of all the sediments flowing east, or around 8% if the Flinders Catchment is included. It follows that if sediment discharges are to be lowered in coastal catchments by an average of 38%, as is being sought by the Great Barrier Reef Marine Park Authority, land uses other than sugar will need to be the target of most attention. Moreover, Cavanagh (2001) failed

![Figure 1](https://iwaponline.com/wst/article-pdf/48/7/35/423628/35.pdf)

**Figure 1** Relations between population growth in coastal Queensland to 1996 and the area of sugarcane, showing a desire for people to live in catchments where sugar is grown. There is no correlation between numbers of people and total catchment size.
to detect residues of superseded persistent organochlorine insecticides in dated sediments off-shore from the Burdekin and Herbert Rivers, despite confirmation that residues remain in cane lands in these catchments.

**Nutrients**

The association between cane lands and nutrient water quality reflects a range of interactions involving inputs, soil types, water balance and management. Sugar is by far the largest user of N fertiliser in Queensland; it also has a long history of P fertiliser applications (e.g. Pulsford, 1996).

By 1994, 64,000 and 7,700 tonnes of fertiliser N and P was used annually on cane in coastal Queensland, with year 2000 consumption around 75,000 and 11,000 tonnes. That is, present annual inputs average 180 and 26 kg of N and P/ha (220 and 22 in the Burdekin region). In addition, around 2 million tonnes annually of mill mud (mean concentration of N and P of 1.48% and 0.91%, respectively) are recycled, presently at rates well above...
immediate crop requirements. A typical application of 150 wet tonnes/ha adds around 560 kg N/ha and 340 kg P/ha.

The effect of inputs over the years has been to increase the P fertility status of over 80% of cane lands. Bramley et al. (1996) noted old canelands in North Queensland contained levels of acid-extractable P approximately five times higher than necessary. From a wider survey, Rayment et al. (1998) reported a Queensland mean concentration for acid-extractable P at 0–250 mm of 85 mg P/kg, four times higher than P critical levels for sugar-cane recommended by Kerr and von Stieglitz (1938) and Chapman (1971). In addition, the arithmetic mean value at 0–100 mm (94 mg P/kg) is higher than critical acid-extractable P levels for other field crops and pastures grown in Queensland (Rayment and Bruce, 1984). Such levels are rated as high in the ratings’ table for the interpretation of Queensland soils, but are lower than levels found in surface soils used for commercial vegetable production (Rayment, 1994). This build in soil fertility is important in the context of water quality, due to confirmation of positive correlations between fertiliser use and nutrient movements to waterways and groundwaters (Addiscott et al., 1991).

The evidence is that historical fertiliser P additions account for at least 30% of the total P in the top 300 mm of canelands in the Northern, Central and Southern regions, and 10% in the Burdekin region (Bloesch et al., 1997), with inputs adding around 1% annually in the 0–300 mm soil zone. It follows that reducing fertiliser P inputs will only slowly lower soil P reserves and the “pressure” on water quality. At soil erosion rates of say 2 to 10 tonnes/ha/yr (between 80 and 90% of the P lost to waterways is attached to suspended sediments) it will take many years to significantly lower the added P that often took over 50 years to supply. Time scales of 30 years or more need to be envisaged, with success assured only if P inputs are seriously curtailed. Soil P tests are available to guide the need for both P fertilisers and mill mud additions, with a cut-off point of around 40 mg P/ha by the acid-extractable test.

Nitrogen budgets for canelands are more difficult to measure with confidence but there are reasonable grounds to suggest from 40%–60% of the applied N is ultimately lost to the environment through gaseous transformations, surface runoff and leaching to groundwater (Bristow et al., 1998).

A stocktake of nitrate in groundwaters associated with several sugarcane areas was undertaken in the late 1990s (Weier, 1999). The samples were from 955 NR&M investigation bores [Maryborough (24); Mackay-Proserpine (271); Burdekin (397); Herbert (57); north Qld (206 – Tully, Innisfail, Gordonvale, Mossman, Atherton, Mareeba)]. Considered collectively, including an additional 73 bores from NSW canelands, 80% of all samples had nitrate-N levels of 2.3 mg/L or less. Corresponding percentages for ranges of 2.3–5.6, 5.6–11.3 and 11.3–22.6 mg N/L were 11, 6 and 3. Specifically, 5% of Burdekin groundwaters tested in excess of the upper limit for drinking water. Also, 3.7 percent of samples from Mackay-Proserpine and 3.5% from the Herbert were in this undesirable category. Isotopic ratios (15N/14N) suggested the majority of the nitrate-N derived from fertilisers.

Earlier groundwater monitoring in the Bundaberg region (Keating, 1997) identified nitrate levels exceeding drinking water standards in some areas. The study concluded that nitrate in the aquifer system was sensitive to the rate of fertiliser N usage on crops of the region (mainly sugarcane and vegetables such as tomatoes). Moreover, there was a clustering of high-nitrate bores in the more permeable soils of the Oakwood – Gooburrum area, north of the Burnett River. Model simulations suggested rates of N leaching between 60–110 kg N/ha/crop on 3 occasions in 35 years for sugarcane.

Nowadays, there is support for the conclusion that from 50–75 kg N/ha is being lost annually from the root zone of cane lands, although not necessarily directly to water. In addition, over 345 kg N/ha is being “held” in subsoils of highly weathered soils in the
Johnstone and Tully Catchments, with a report of a build to 500 kg N/ha at Bundaberg. Refer to Rayment (2002) for more details on these findings. The nitrate storage limit of these soils will be exceeded if present practices continue unabated.

Detailed monitoring and modelling in the Johnstone Catchment (Hunter and Walton, 1997) highlighted the disproportionate (higher) losses from canelands of labile forms of N (nitrate) and P (orthophosphate) in that tropical environment. For the first half of the 1990s, almost 50% of the nitrate in the river discharge came from canelands, even though these occupied only around 13% of the catchment. Moreover, the average annual catchment loss of 752 tonnes of N partitioned as ≈50% in sediment, 27% as nitrate-N and 3% as ammonium-N. Modelled estimates of total N and P lost from Queensland’s east coast catchments (totals of around 8,800 tonnes of N and 1,300 tonnes of P) are shown for comparative catchment purposes in Figure 4. Estimated quantities are greatest in the smaller, wet catchments where cane occupies > 10% of the area. Corresponding tonnages associated with grazing lands in coastal Queensland are each approximately six times higher.

There is no quick soil testing procedure to guide N fertiliser use in canelands. It follows that if nitrate and total N concentrations lost to water are to be lowered by 39%, as has been suggested, N fertiliser inputs will need to be lowered in a manner that ensures an acceptable balance between optimising yield and minimising losses to waterways. It will be hard to convince growers to significantly and voluntarily lower their N fertiliser use, unless they can be advised with confidence the cost to yield will be insignificant. There will also need to be greater awareness of the externality costs in resource economic terms (Mallawaarachchi et al., 2002).

**Heavy metals**

CRC Sugar data exist for total heavy metal concentrations in Queensland canelands (Rayment et al., 1997). Using mean data from the 0–100 mm depth interval and assuming there is no heavy metal enrichment in run-off, averages of 4.9, 0.06, 17, 107, 23, 0.08, 1.1, 32, 24, 0.45, 0.20 and 61 grams of As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, Ti and Zn, respectively, will be lost with each tonne of surface soil moved to waterways (Rayment, 1999). Interestingly, these metal concentrations, apart from Cu, differ markedly from total heavy metal concentrations in sediments from fresh-water zones of some “reference” Queensland rivers reported by Semple and Williams (1998). While the magnitudes of the differences were hard to reconcile (median Cd concentration in sediments 25 times higher; total Cr, Ni, Pb and Zn around 1.6, 1.6, 4.8, and 1.4 times lower than corresponding mean values).
concentrations in Queensland canelands), total heavy metals can serve as useful “finger-
prints” of sediment sources.

**Dissolved oxygen (DO)**
Low DO concentrations have adverse effects on many aquatic organisms (e.g., fish, inver-
tebrates, and microorganisms) that rely on DO for efficient functioning and survival. In
addition, low DO promotes reducing conditions that facilitate the release from sediments of
nutrients such as P and metal toxicants to the water column. Water temperature and chlorin-
ity affect how much oxygen water can dissolve. For example, at 20°C and with zero
chlorinity, 6.0 mg O₂/L is 67% saturated. Zero chlorinity water at 25°C at the same DO
concentration is approximately 72% saturated. Contemporary national guidelines suggest
DO “trigger values” for slightly disturbed ecosystems for lowland rivers of 85 through to
110% saturation and 85 through to 120% saturation in tropical Australia). It is known that
levels fluctuate between day and night and are typically at their lowest (most stressful to
biota) soon after dawn and when oxygen-rich oceanic waters are not influential.

Typical 50th percentile “unpolluted” DO values reported for the period January 1988 to
December 1991 for Qld streams and estuaries were around 85–90% saturation. At that
time, most of the 10th percentile DO values were in the immediate vicinity of treated
sewage discharges, although storm events that transferred organic matter to the waterway
were sometimes implicated (Anon, 1993). More recently, Wilhelm (2001) reported trends
in DO at 18 sites nearby to sugarcane in coastal Queensland for the period 1st May 1995 to
30th April 2000. Lowest levels (< 5 mg O₂/L) were detected in the Plane, Burrum (Elliott
River) and Maroochy Catchments.

Prior to the 1990s, fish kills due to hypoxic or anoxic water in cane areas were mostly
believed to be associated with releases of sugar juices and vapours from sugar mills and dis-
tilleries. Point-source discharges, now in control, typically contained five-day biochemical
oxygen demand (BOD₅) values of 20–100 mg O₂/L (Moss and Bennett, 1991). However,
sporadic reports of fish kills in cane growing areas continued, often attracting close media
attention. Indeed, the 1998 super-wet spring-early summer of central and northern
canelands of Queensland saw reports of kills of fish and other aquatic fauna (such as
shrimps and eels) at multiple sites within or downstream of cane-growing areas. The major-
ity opinion, mostly based on anecdotal associations, linked non-point source freshwater
runoff and low in-stream levels of DO as probable causes.

A subsequent CRC Sugar study (Rayment, 1999) concluded the most likely cause to be
sugar juice lost during mechanical cane harvesting. It was postulated that cane juice (most-
ly water soluble sucrose) can transfer to the soil and potentially to water under both burnt
and GCTB systems. Moreover, this highly labile form of carbon (C) was expected to create
a significant BOD₅, particularly during wet-weather harvesting or in irrigation runoff water
soon after harvest. It was conservatively estimated that at least 0.23, 0.33, 0.26 and 0.23
to 2.400 mg/L) in water
after soaking freshly harvested cane trash for several hours; and occasional periods when DO concentrations in local waterways have plummeted and remained low for days.

In practice, the loss of sugars to soil only becomes an environmental issue if there is subsequent movement to waterways. As an example, 100,000 L of runoff water with a BOD$_5$ from sugars of 260 mg O$_2$/L would eventually strip the oxygen from 4 ML of receiving water with an initial DO concentration of 6.5 mg O$_2$/L. The consequential effects on in-stream fauna are obvious. In addition, concentrations of DO can be lowered very quickly (minutes to hours) due to chemical oxygen demand (COD) associated with reactions such as the oxidation of Fe$^{2+}$ released in drainage from acid sulfate soils (ASS). For example, 20 mg/L of Fe$^{2+}$ is equivalent to a COD of 1.4 mg/L of DO, assuming 50% oxidation to Fe$^{3+}$ occurs. Flow weighted average concentrations of Fe$^{2+}$ in drainage from an ASS site at Rocky Point, used for cane for over 30 years, have ranged from 12–33 mg Fe/L (Cook et al., 1999). Extended periods of low DO recorded in waterways near to that experimental site (Rayment, 2002) may be due to COD or a combination of BOD$_5$ and COD.

**Pesticides**

Residues of several pesticides and their metabolites have been detected over the past 25–30 years in water, sediments and biota, mainly in Queensland’s coastal zone (Rayment et al., 1997). These detections often included superseded organochlorines (DDT and metabolites, dieldrin, heptachlor epoxide, chlordane), which had a range of uses in cities, farms and factories. Closely linked to sugar was the confirmed presence of low concentrations of atrazine (including decomposition products) in 30 to 76% of groundwaters of the Burdekin Delta and the Lower Burdekin River Irrigation Area (Bauld et al., 1995).

Hunter et al. (1996) reported the detection of residues of superseded organochlorines as well as 2,4-D, atrazine and 2,4,5-T (now superseded) in biota from the Johnstone River Catchment, but only 2,4-D was detected in biota from the Daintree River. Importantly, fewer pesticide residues were found than was the case in the 1970s, probably due to enhanced pesticide use practices and changes in the product mix.

Since then, the Sugar Industry has adopted a transparent approach to its use of pesticides through a publicly available, comprehensive pesticide use audit for Queensland on a product, mill area and catchment basis (Hamilton and Haydon, 1996; examples in Figure 5). Less is known of the market penetration and environmental consequences of emerging products such as Flame (imazapic), Confidor (imidacloprid), and Balance (isoxaflutol).

Findings from research and monitoring in fields and waterways in or near canegrowing areas indicate concentrations of herbicides in excess of ANZECC guidelines for ecosystem protection can leave the farm soon after application if significant run-off occurs (Rayment, 2002). For example, a one in two year runoff event in February 2002 caused an estimated load of 470 kg of diuron to enter Dumbleton Weir on the Pioneer River, which is downstream of canegrowing areas (Simpson, 2002). Detectitions of ametryn, atrazine (and desethylatrazine), hexazinone and 2,4-D were also reported. In contrast, monitoring of major cane drains in northern NSW indicates some areas have measurable losses and others don’t. In that study, no residues of glyphosate were detected in any NSW cane drain, probably due to its ability to bind to cations already adsorbed to soil, irrespective of soil pH (Carlisle and Trevors, 1988).

Downstream, reports indicate the herbicide diuron is present and persisting in estuarine and marine sediments at concentrations sufficient to adversely impact on photosynthesis of seagrass species preferred by dugongs (Haynes et al., 2000b) and perhaps mangroves such as Avicennia marina (Duke et al., 2001). Data for a range of locations along the north Queensland coast provides convincing evidence of wide distribution, but the source/s of the diuron have not been resolved. What is more, other pesticide users that share catch-
ments and active ingredients in common with sugar have not quantified their patterns and quantities of use. The off-shore diuron concentrations (Haynes et al., 2000a) were 0.0005–0.0017 mg/kg in 3 of 16 intertidal sediment sites sampled in 1997. The range in 14 of 25 sub-tidal sediments was 0.0002–0.01 mg/kg from the same region in 1998, and the range in corresponding seagrasses was 0.0008–0.0017 mg/kg dry wt. There are also unpublished reports of low but measurable concentrations of diuron in Harvey Bay, in downstream locations of the Mary and Pimpama Rivers in south Queensland, and in sugar-irrigation tail-water in the Burdekin at typical concentrations of 3–25 µg/L. Nowadays, diuron has many uses beyond sugarcane. One is as an active ingredient in around 30 registered formulations now used in Queensland waters on boat hulls for antifouling and slime control purposes.

Strongly acidic water
Sulfuric acid is mobilised following the oxidation of pyrite, jarosite and related minerals in ASS. This strong acid and its reaction products, when allowed to form in or drain to waterways, can result in serious acidification of streams and estuaries, stripping DO and adversely affecting ecosystem health (Sammut and Lines-Kelly, 1996). The most obvious and damaging impacts of ASS have been on gilled organisms in estuaries. Fish-kills and crustacean-kills reported in coastal Australia since the mid-eighties (Easton, 1989) have been associated with low water pH ($\leq 3$) and/or Al toxicity in the pH range 3–6.5. In addition, water pH values of $\leq 3.5$ have been linked to a range of undesirable impacts on water-plants, amphibians, biological processes and habitat value.

At pH 3, common in estuarine waters affected by major discharges from ASS, the acid alone can cause necrosis and sloughing of epithelial cells (fish skin) and epithelial lifting. This damage increases as aluminium concentrations increase. Fish are also more susceptible to epizootic ulcerative syndrome (red-spot disease; associated with infection by *Aphanomyces invadens*) when epithelial cells are damaged by acid.

Twenty-one percent of canelands in south-east Qld (20,000 ha) are at potential risk from ASS with mapping a current activity. Lesser areas are thought to exist in canelands of central and north Qld but detailed ASS risk mapping is incomplete in those regions (Powell and Ahern, 1999). It follows that strongly acidic waters can be an occasional water quality issue for 10–20% of canelands in eastern Australia. However, the risk has been lessened with the release of a national strategy for the management of coastal ASS and much improved understanding of the management of ASS in cane-growing areas (e.g. Beattie et al., 2001).

**Figure 5** The “top seven” pesticides on an active ingredients basis used annually in cane production systems of Queensland [adapted from Hamilton and Haydon (1996)]
Benchmarks of surface water quality

Mitchell et al. (1991) provided an early comprehensive collation of nutrient concentrations and fluxes in north Qld coastal rivers and streams. Data (from 5 to 142 samples per stream) were from Birthday Creek to the O’Connell River. The main features were wide fluctuations in nutrient concentration, with suggestions of higher concentrations in wet seasons. Mitchell et al. (1991) noted that nitrate-N concentrations appeared to increase downstream in some rivers adjacent to sugarcane cultivation. In addition, there were suggestions that nutrient concentrations (particularly nitrate) increased in the first flushes after dry periods, an observation subsequently supported by Crossland et al. (1996).

Surface water quality data for 16 locations in the Johnstone Catchment were reported in late 1993 (Hunter, 1993). Six of the sites were quantitative as they were supported by flow data and had sampling intensities up to 18 times daily during rare periods of moderate to high flows. In a period of low rainfall, up to 36% of dissolved N loads came from rainfall, suspended solids were predominantly low (<10 mg/L), reactive and total P at all but one site were < 0.05 and <0.01 mg/L (good), while one or more forms of mineral or total N showed relatively high concentrations at half the sites on occasions. Concentrations of total N sometimes exceeded the then indicative upper concentration for ecosystem protection of 0.75 mg N/L.

In the lower Herbert Catchment, canelands were the greatest source of suspended solids in streamwater, with little sediment sourced from land supporting native and plantation forestry or cattle grazing. For the area studied, however, there was no clear evidence of an increase in sediment concentrations moving downstream as was the case for nutrients. In addition, concentrations of total soluble N and orthophosphate P in streams associated with sugarcane in the lower Herbert were generally greater than those associated with other land uses, and any differences between these were only seen during wet season peak flows. Also, nutrient (N and P) concentrations in the Herbert River at Ingham were greater than at Abergowrie, 32 km upstream, indicating an export of nutrients from land draining into the Herbert between these points (Bramley and Johnson 1996).

The 160-page publication Testing the Waters (DEH & DNR, 1999) contains spatially referenced physicochemical and biological data on surface waters and physicochemical data on groundwaters. Parameters reported include DO, electrical conductivity (EC), turbidity, total P, oxidised N (nitrate), chlorophyll $a$, surface water macroinvertebrates, etc. Few “sugar” waterways were included in a separate grouping of rivers and estuaries with “high concentrations in selected parameters” (EC, turbidity, oxides of N, total P, chlorophyll $a$ and DO), probably due in part to the relatively low numbers of sites in cane-growing areas and/or a general lack of “event-based” monitoring.

Conclusions

Water within, moving through, and discharged from canelands in eastern Australia has emerged across the last decade as an important environmental and emotional issue for the industry. Habitat loss and regular media attention on possible downstream impacts have influenced community perceptions. Much has been done and documented (Rayment, 2002) to quantify “pressures” the sugar industry and at times other land and water users have or are having on nearby water quality.

The industry has lessened soil movement to waterways in recent years, much due to the wide adoption (≈ 70%) of GCTB. However, the heavy use of fertilisers and to a lesser extent the recycling of mill muds on canelands exert on-going “pressure” on nutrient water quality for ecosystem protection, both on- and off-shore. As indicated for phosphorus by Bloesch et al. (1997), there will be a lag of many years for the benefits of lower fertiliser inputs to be reflected in better water quality, due to the build in soil fertility that presently exists in most well established canegrowing areas.
While point source causes of low DO in sugar mill effluent have largely been resolved, diffuse causes may be increasing, based on recent monitoring. Growers in areas with ASS need to be vigilant to limit the liberation of $\text{Fe}^{2+}$ to water, due to its significant COD. There is also a need for better guidance on acceptable organic matter loadings, including the significance of cane juice and billet losses during mechanical harvesting. For example, New Zealand experience with lactose sugar in dairy effluent (Smith et al., 1993) suggests that BOD$_5$ values as low as $< 5 \text{ mg O}_2/\text{L}$ can be responsible for downstream occurrences of sewage fungus growth. While improved cane harvester designs will help, the emerging evidence that very little sugar can promote high BOD$_5$ concentrations indicates on-farm management practices to minimise movement of highly labile C to waterways via run-off will be needed. Preliminary guidelines are available (Rayment and Bohl, 2002).

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