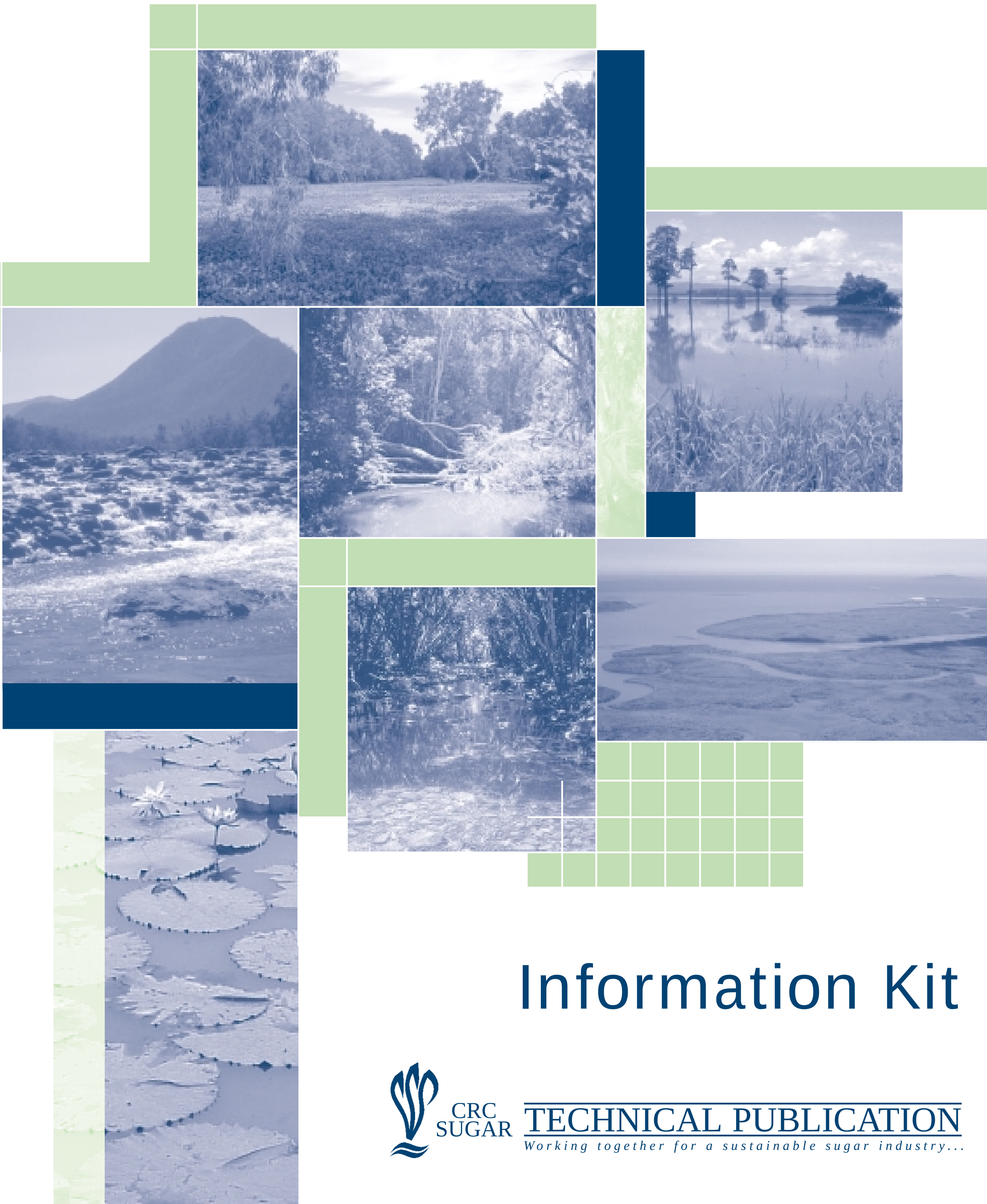
Understanding

Dissolved Oxygen in Streams



Information Kit

CRC SUGAR

TECHNICAL PUBLICATION

Working together for a sustainable sugar industry...

PURPOSE OF THIS INFORMATION KIT

These CRC Sugar information notes and extension resources are intended for use by industry extension advisors to provide technical information on dissolved oxygen (DO) in waterways where sugar cane is grown. The kit emerged from community concerns that farming practices could contribute to the depletion of DO in nearby water courses, causing fishkills and other problems for aquatic fauna.

THE INFORMATION KIT WILL ASSIST ADVISORS TO:

1. raise industry awareness and understanding of DO fluctuations and their causes;

2. generate discussion on preferred management practices to achieve desired levels of DO; and

3. integrate the knowledge into current farming systems.

THE KIT IS APPLICABLE TO ALL CANE GROWING DISTRICTS, AND INCLUDES THE FOLLOWING COMPONENTS:

i. Information notes for extension advisors;

ii. A ®Microsoft Power Point presentation on DO, designed to incorporate local information (on CD);

iii. Information Sheets for distribution to those who have attended a presentation on DO oxygen in streams. The sheets provide 'take home' information on:

- *What is Dissolved Oxygen and Why Does it Fluctuate?*
- *Which Aquatic Plants Influence Dissolved Oxygen?*
- *How to maintain Dissolved Oxygen at Preferred Concentrations;*

iv. A listing of current research activities and contacts for water quality monitoring and advice.

ADDITIONAL KITS ARE AVAILABLE

Copies of Information Sheets or further information on the Kit are available from the CRC for Sustainable Sugar Production (CRC Sugar).

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INFORMATION SHEETS

1. What is Dissolved Oxygen and Why Does it Fluctuate?

2. Which Aquatic Plants Influence Dissolved Oxygen?

3. How to maintain Dissolved Oxygen at Preferred Concentrations.

INTRODUCTION

Dissolved oxygen (DO) is an important water quality parameter because it influences the living conditions of all aquatic organisms that require oxygen. Urban, industrial and agricultural activities and natural occurrences in catchments all affect DO levels in streams and other water bodies.

Recent fish kills in north Queensland coastal catchments highlighted the lack of information available on DO. Greater understanding of the factors driving DO concentrations in waterways and interaction with land based processes including farming and the specific causes of DO depletion is vital for sustainable land and water management.

There is a community expectation that agricultural practices will have minimal adverse impacts on water resources and the plants and animals dependent on those resources. For example, coastal wetlands are a critical habitat in the life-cycle of approximately 70% of the commercial fishery of coastal Qld.

This Information Kit is intended to assist cane growers to develop and adopt practices that ensure favourable and consistent levels of DO in nearby waterways and water storages.

1. WHAT IS DISSOLVED OXYGEN AND WHY IS IT IMPORTANT?

DO refers to the oxygen present in water. Concentrations are commonly reported as milligrams/litre (mg/L) or as percentage saturation (saturation equalling 100%). Supersaturation (>100%) exists when "free" oxygen is present within the water body, a situation that arises when net photosynthesis is greater than total oxygen consumption.

Measurements of DO reflect the balance between oxygen use (consumption) and oxygen production. In waterbodies, oxygen is produced by:
1. photosynthesis by aquatic plants,
2. the physical transfer diffusion of oxygen from the atmosphere to the water.

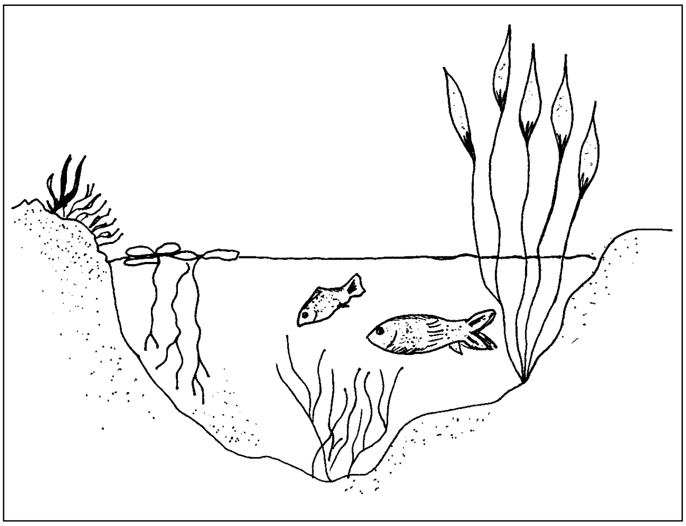


Figure 1. *Several factors influence production and consumption of DO.*

Oxygen dissolved in water is consumed or lowered by:
1. aquatic plants and animals through respiration,
2. decomposition of organic matter by microorganisms producing a Biological Oxygen Demand (BOD).
3. chemical reactions requiring oxygen – producing a Chemical Oxygen Demand (COD), and
4. heating to temperatures exceeding 25-35°C, as such temperatures lower the water solubility of oxygen, which is highest in cold water *(see Table 1)*.

When saturated, fresh water at 0°C can hold up to 14.6 mg/L of oxygen. Anoxia is the term used to describe water devoid of oxygen. Hypoxia refers to low levels of DO in water.

Table 1. *Saturated dissolved oxygen concentration at various temperatures in fresh water and seawater.*

Temp ^{o}C	**Saturated DO Concentration (mg/L)**	
	fresh water	seawater 35ppm
0	14.6	11.5
15	10.1	8.1
20	9.1	7.4
25	8.2	6.8
30	7.5	6.2

Ref: Colt, J., (1984) Computation of dissolved gas concentrations in water as functions of temperature, salinity & pressure. *American Fisheries Society Special Publication*, **14**.

1.1 DISSOLVED OXYGEN SUPPORTS AQUATIC LIFE

Many aquatic organisms such as fish, invertebrates (e.g.. insect larvae) and aerobic microorganisms depend on DO for respiration. Exposure to low oxygen may cause a slowing in growth rates, reproductive difficulties, stress, susceptibility to disease, and in severe cases of depletion, premature death.

When DO falls to levels below 5 mg/L, mobile aquatic fauna prefer to move to areas with sufficient DO. If such water is unavailable, fish often move to shallow water and may "gulp" air. Non-mobile species suffer because they are unable to avoid the low-oxygen water. Continued decline to very low levels of DO (e.g. <1mg/L), will result in severe stress and occasional death of all organisms requiring "normal" levels of DO (> 5 mg/L). A rapid rate of decline in DO can cause a catastrophic "crash" and subsequent suffocation.

The oxygen requirements of fish and in-stream macro-invertebrates differ between species. Different life stages (i.e., eggs, larvae, juveniles and adults) of aquatic fauna may also have different oxygen needs.

Draft 1999 ANZECC guidelines state that DO levels below 5 mg/L are stressful to most aquatic fauna. Any long term (chronic) reduction in DO levels is likely to lower the diversity (mix) of species and total numbers of organisms within species. This can impact adversely on aquatic food webs and fishery production.

A change in the mix (diversity) of organisms to comprise a lack of species intolerant to low DO, or dominance of more tolerant species, are all indicators of low DO, but may also be due to other causes.

> Of all aquatic fauna, fish tend to be the least tolerant to low DO. As a general rule, if all life stages of all fish are supported, healthy invertebrate communities should also remain.

1.2 AQUATIC CHEMISTRY OF OXYGEN

Stable DO levels above 5mg/L at the water's surface are also essential for normal chemical reactions that continually occur in rivers and streams. Low DO promotes the accelerated release of phosphorus and toxins such as heavy metals from sediments. Low DO can also prevent the detoxification of ammonia in water by nitrification. Ammonia is directly toxic to many aquatic organisms.

2. WHY DOES DISSOLVED OXYGEN FLUCTUATE?

DO levels can change very quickly and fluctuate significantly through a 24-hour period. A typical daily trend is shown in Figure 2.

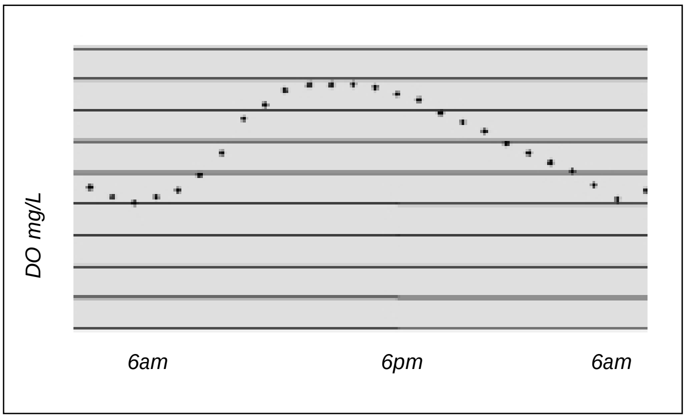


Figure 2. *Typical DO concentration over 24 hours, 6am – 6pm.*

Over a typical diurnal (24hr) period, the oxygen consumed by plant respiration is less than the oxygen produced by photosynthesis. However, during periods of overcast weather, oxygen production is reduced and oxygen consumption by plant respiration can exceed oxygen production, leading to DO decline.

Table 2 indicates the relative significance of the different sources and losses of oxygen in a typical system.

Table 2. *Oxygen budget for an urban estuary*

Function	**kg O_2/day**	**% of total**
Additions:		
Accrual	76	13
Aeration	225	45
Photosynthesis	214	42
TOTAL	**515**	**100**
Losses:		
Export	30	5
Deaeration	89	14
BOD	91	14
COD	?	?
Plant respiration	97	15
Benthic respiration	335	52
TOTAL	**642**	**100**

(Connell et al.)

2.1 ATMOSPHERIC EXCHANGE

The transfer of oxygen from the air to the water's surface is an important exchange pathway. This exchange is greatly increased by mixing or turbulence from wind, waves, currents and tumbling movement over rocks, etc. Hence, steep graded streams with rapids or riffle zones are generally closer to 100% oxygen saturation than stagnant water bodies.

2.2 MICROBIAL RESPIRATION

Breakdown of organic matter in water is an important process in aquatic food webs. It also has the greatest potential to decrease DO levels. This is because micro-organisms, such as bacteria, rapidly break down available organic matter, consuming oxygen in the process. For example, herbicide use on aquatic plants will cause plant death and subsequent decay. This favours increased microbial activity by aerobic organisms, resulting in a reduction in DO for as long as a source of labile organic material remains available. The amount of oxygen consumed by microorganisms to break down organic matter is measured as Biological Oxygen Demand (BOD). BOD reflects potential consumption of dissolved oxygen in mg/L and is usually measured, at a fixed temperature of 20^{o}C, after a number of days (i.e. 5 days for BOD^5).

2.3 CHEMICAL PROCESSES

The amount of oxygen consumed by chemical processes is known as Chemical Oxygen Demand (COD). The addition of substances to water that readily react with oxygen (such as ferrous iron) exacerbates the COD. Both COD and BOD can occur simultaneously, adding to the pressure on DO levels.

2.4 TEMPERATURE

The ability of oxygen to remain in the solution decreases as water temperature increases *(Figure 3)*. Temperature also increases the metabolic rate of organisms, resulting in increased consumption of oxygen. As a result water temperature has a significant influence on DO levels. Under tropical or hot weather conditions, high respiration rates and reduced water solubility of oxygen work together to lessen natural DO concentrations relative to temperate or cold weather conditions. Differences in temperature can also cause waterbodies to stratify into layers. This is particularly common in deep (e.g. > 3 - 5 metres) water storages and pools. Stratification prevents the transfer of DO to depth, creating oxygen-poor "bottom" water. The occurence of rain, wind, current, or a change in temperature can cause mixing across stratified layers. In Qld, this typically occurs at the onset of winter conditions in June or July, summer rains may also trigger mixing.

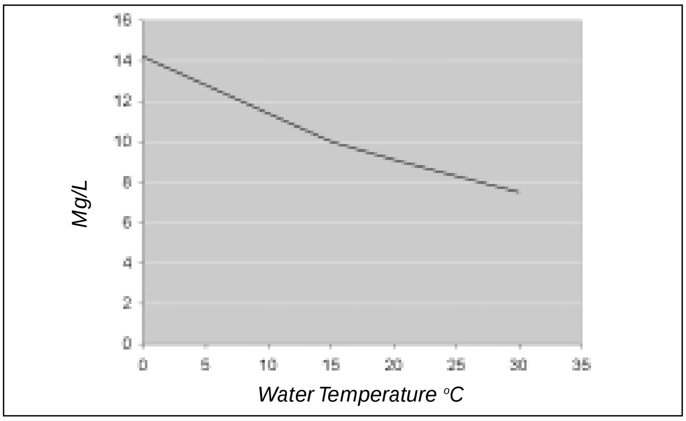


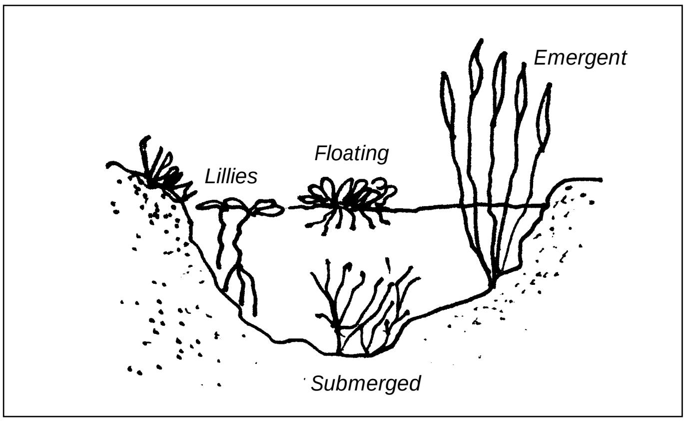
Figure 3. *Solubility of oxygen in fresh water.*

2.5 AQUATIC PLANTS

The actual influence of aquatic vegetation on DO is complex and not well understood. Excessive growth of aquatic flora (i.e. cyanobacteria, algae and macrophytes) is known to occur as a result of excess nutrients, light availability and through lack of natural competition. Section 3.0 of this document outlines the impacts that different types of aquatic plants can have on DO.

3. WHICH AQUATIC PLANTS INFLUENCE DISSOLVED OXYGEN?

3.1 SUBMERGED AQUATIC PLANTS



Submerged aquatic plants, such as algae, transfer oxygen into the water during the day through photosynthesis. As a general rule, such plants produce about six times more oxygen through photosynthesis than they consume through respiration during a day. Under low light conditions (night and cloudy days), these submerged plants are net consumers of oxygen, contributing to oxygen demand.

> The oxygen contribution of submerged aquatic plants is often equalled by the waterbody's total consumption of oxygen by respiration.

Algae usually exist alongside other aquatic plants in waterways, adding to the in-stream biomass. This has significant implications for DO, as detailed in the following sections.

3.2 FLOATING AQUATIC PLANTS (MACROPHYTES)

> Very low DO levels (below 1% saturation) are common under floating vegetation mats that completely smother water bodies.

Floating aquatic weeds can cause severely low DO levels through the following processes:

1. As a large floating mass, they physically block the transfer of oxygen from the atmosphere to the water's surface. This effect occurs with plants such as water hyacinth, salvinia and water lettuce.
2. Floating weeds block light and prevent photosynthesis (oxygen production) by submerged plants. However oxygen consumption continues at depth and DO reductions can be extreme.
3. Free-floating plants do not contribute directly to increase DO in water as they exchange gas with the atmosphere.
4. Extensive root systems in the water provide a large surface area for the growth of microbes, which rapidly consume DO.

5. These plants generate a constant shower of organic matter from their root systems, which contributes to BOD loads.
6. Floating plants are capable of using nutrients in the water column very effectively but are unable to directly access nutrients stored in bottom sediments. However, under anoxic conditions, nutrients (particularly phosphorus) are released from sediments into the water column where they become directly available to the floating plants – increasing plant biomass.
7. Death and decay of floating plants provides the conditions for a further depletion of DO levels.

3.3 ATTACHED EMERGENT PLANTS

When emergent plants are relatively sparse, they support the growth of algae, which in turn contribute to DO by photosynthesis. However, as emergent plant densities increase, shading prevents photosynthesis by the algae. Eventually microbes which exert an oxygen demand, replace the algae. Therefore at high plant densities, emergent plants can cause significant DO depletion.

Similar to floating plants attached emergent plants such as para grass, sedges & reeds do not contribute DO to waterbodies as they exchange gas with the atmosphere. Some species transfer oxygen into the sediments via roots, however this process does not significantly influence DO levels in the water column.

HOW BAD IS PARA GRASS?
(Brachiaria mutica)

The high biomass and surface area of para grass can support large populations of microbes, which exert very high oxygen demand. Para grass also tends to scramble over other floating vegetation, binding it together and preventing its removal during floods. This has the effect of prolonging the floating vegetation's influence on in-stream DO levels.

Para grass also promotes siltation of streams. This acts to reduce stream capacity, limits upstream and downstream movement by mobile fauna, and increases the opportunity for local flooding.

3.4 NATIVE PLANTS AND WATER LILIES

Native aquatic plants such as water lilies do not appear to have the same negative impact on DO levels as floating mats of vegetation. Water lilies are less effective at blocking oxygen transfer from the atmosphere to the water column. Water lilies attach to bottom sediments and only inhabit certain depths, often preventing them from colonising entire water bodies.

Species such as water lilies can occur at relatively high densities without significant adverse impacts on DO (although oxygen concentrations may still be below saturation).

4. MONITORING DISSOLVED OXYGEN

Daily highs and lows of DO are known to occur around mid-afternoon and early morning respectively. In tidal areas, the situation is exacerbated when low tides occur around dawn. Such fluctuations can make the results of monitoring difficult to interpret, when "spot" sampling is involved. Continuous 24 hour monitoring is preferred, providing details of stream flow are also available. "Spot" sampling of DO is useful if performed to a strict timetable (eg. at the same time of day for each sampling) and more intensively around runoff events.

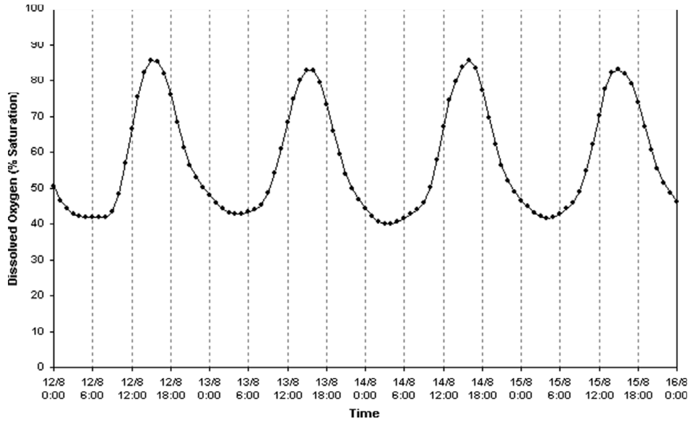


Figure 4. *Daily trends in DO influence preferred sampling times.*

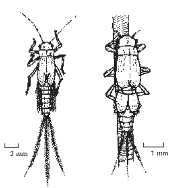
Current Monitoring Activities

- Officers of Qld's Environmental Protection Agency carry out monthly water quality monitoring on some waterways.
- DNR has been continuously monitoring DO levels in the Pimpama Catchment, south-east Qld for around two years. There are 5 remote water-monitoring stations located at strategic points in the catchment, including sugar-growing areas of Sandy and Hotham Creeks.
- DO levels are being monitored in six drainage systems of northern NSW canelands as a component of a larger CRC Sugar funded water quality monitoring program
- Organisations with a license to discharge from point sources are required to monitor discharge water and receiving waters.
- Community programs such as Waterwatch (Qld) and Riverwatch (NSW) monitor water quality in priority streams.

Using Biological Indicators

Macro-invertebrates are emerging as promising indicators of water quality. Macro invertebrates have different species abundance and diversity depending on the quality of the water body. Those **intolerant** of low DO include *Ephemeroptera,* some *Trichoptera* and *Odonata*. Those showing **some tolerance** to low DO are a few *Trichoptera* and *Odonata, Chironomidae, Lepidoptera, Gastropoda,* and *Caridina.* **Tolerant** groups include *Oligochaeta* and *Chironomidae* and a few air-breathing insects.

Macro-invertebrates have also been used to "calibrate" chemical tests for DO in waterways of the Wet Tropics. Suggested broad categories are shown in Table 3.



Sustained DO (mg/L)	Degree of impact
< 3.5	Severe
3.5 - 5.0	Moderate
5.0 - 6.5	Mild
> 6.5	Clean water

Table 3. *Suggested broad categories for DO levels as indicator of water quality impact.*

4.1 KEY STEPS TO MONITORING DO

1. Seek advice from your local EPA office, Waterwatch, Riverwatch or ICM group *(See Appendix 1).*
2. Have clear, achievable objectives on what you are monitoring and why.
3. Understand the nature and behaviour of DO. This can influence where, when and how you monitor.
4. Select monitoring techniques – consider cost, time, difficulty of operation, availability, accuracy and reliability.
5. Select sampling sites which are representative of the water body – avoid drop structures, bridges, culverts, weeds, stagnant sections etc which may artificially influence DO readings.
6. Take measurements directly from the waterbody (in-situ) rather than taking sample(s) for later analysis. This will prevent inaccuracies caused by changes in temperature or through continued chemical processes in the sample.
7. Take measurements or samples early in the morning and as often as possible to obtain the range of oxygen levels and trends over time.

Generally, sampling throughout the year is preferable to establish a clear picture of DO trends. However, as warmer conditions tend to pose the greatest risk of DO depletion, sampling through spring and summer will provide the most important data.

4.2 RECOMMENDED DO LEVELS FOR ECOSYSTEM PROTECTION

The 1992 ANZECC Guidelines recommend that DO should not fall below 6 mg/L or 80 – 90% saturation over at least one 24 hour period.

Proposed ANZECC (1999) guidelines require consideration of ecosystem type, desired level of protection, and availability of adequate data and reference areas for comparison. Under these draft guidelines, variation in DO concentration and aquatic species composition are considered the most appropriate indicators of DO problems.

Interim 'trigger' guidelines (Table 4) have been proposed. If measurements exceed guideline levels, further detailed monitoring of BOD is recommended. The development of reference data-sets are also proposed. Reference data obtained from similar ecosystems (free of disturbance) could then be used to compare water quality analyses.

Table 4 *Draft ANZECC Interim Trigger Guidelines. Compare mean DO concentration measured under low and high temperature conditions with the suggested trigger levels. If DO concentrations measured are lower than the trigger levels, there is an increased risk of adverse biological effects and further investigation is required.*

Ecosytem Type	DO% Saturation
Lowland River	90
Upland River	92
Freshwater Lakes	90
Wetlands	90
Estuaries	90
Coastal and Marine	90

Note. Mean DO concentration is calculated using the average lowest daily DO concentrations.

4.3 MONITORING EQUIPMENT

A range of equipment is available for DO analysis. Most are reliable if used correctly, however some techniques are more complex and/or require more time and cost to complete.

4.3.1 Electronic DO Meter

DO meters offer flexibility and efficiency of operation. DO is read electronically, via a sensor emersed in water. Options are available with most units to measure additional parameters such as pH, conductivity and temperature. Some are able to automatically log readings on a minute or hourly basis without the operator present. This provides a more thorough record of DO fluctuations over a period of time.

Currently, the cheapest available unit is approximately $1100. Probes can be easily damaged and some are considered not suitable for field use. All meters require regular calibration and maintenance. Most DO meters have good accuracy, typically better than 3% and some close to 1%. If many or continuous measurements are required, then DO meters are used.

4.3.2 Modified Winkler Titration

Some Waterwatch groups in Queensland use this technique. An accurately measured amount of reagent is added into a fixed sample until a colour change occurs. The quantity of reagent used is then incorporated into a simple formula to calculate the DO content of the sample. Equipment and chemicals for this technique are inexpensive and readily available. Kits are marketed for approximately $180. These kits contain sufficient premeasured reagents for up to 100 tests. These kits are cheap and easy to use, but have limited accuracy, typically from 5-10%. Also, if many measurements are made, then this method becomes expensive.

4.3.3 Colorimeter

Hach Model DR/700 colorimeters are portable, digital units, capable of measuring a wide range of parameters, such as DO, nitrate, nitrite, ammonia, phosphorous, COD, by substituting filter modules. These units cost around $1900, plus up to $250 for each module. Supply of reagents is an ongoing operating cost. Mackay BSES and some Waterwatch Queensland groups use this test kit.

5. WHO IS RESEARCHING DISSOLVED OXYGEN?

Until recently, little research had been undertaken in Australia on DO associated with diffuse (non-point source) pollution of waterways. Accordingly, little information is available on the processes influencing DO in Australian aquatic systems, including those draining canelands.

The recent spate of fishkills in cane growing areas, in which DO was considered to be a significant factor, has triggered some research activity. Investigations are currently underway into:

1. The oxygen requirements of different aquatic organisms,
2. Factors influencing DO,
3. Potential impacts of farming practices on DO levels, and
4. Management options.

Research Initiatives

COOPERATIVE RESEARCH CENTRE FOR
SUSTAINABLE SUGAR PRODUCTION

Understanding Causal Factors of Oxygen Depletion in Waterways of Cane Growing Regions

Objectives

1. Collate, review and analyse historical data on DO in waterways in selected cane growing areas
2. Identify and understand sources/pathways which cause low DO in cane growing catchments
3. Analyse, understand and prioritise the relevant processes (e.g.. trash, fertiliser, rainfall)
4. Develop agreed recommendations to minimise impacts

Water Quality Pressures and Status in Canelands

This CRC Sugar review includes information on DO, with a focus on canelands.

SRDC Project No. JCU016
(Australian Centre for Tropical Freshwater Research – James Cook University)
Quantification of Effects of Cane Field Drainage on Stream Ecology

Sugar Research and
Develpment Corporation

Objectives

1. Undertake field studies to quantify/describe the temporal and spatial variation of DO in waterbodies, and;
2. Quantify the effects of low DO on aquatic animals

Experimental studies currently focus on:

- lethal effects (i.e.. at what DO level does significant mortality occur) and,
- behavioural responses to low DO (e.g. avoidance of low DO water)

6. HOW CAN I HELP PREVENT PROBLEMS WITH DISSOLVED OXYGEN?

Many aquatic systems are finely balanced and are subject to natural fluctuations. Management practices will not eliminate all causes of low DO levels in waterways, many of which are influenced by seasonal conditions. However, management can help improve the general health of waterways, which may in turn help prevent unnatural occurrences or reduce their severity.

6.1 MINIMISE SEDIMENT LOSS

Soil loss can result in elevated turbidity levels, which causes plants to consume more oxygen than they produce. Under high turbidity, DO levels in waterways will decline and will not recover until sufficient light penetration allows photosynthesis to resume at optimum rates.

Reduce in-field soil losses:

- Use green cane trash blanketing wherever possible to minimise soil cultivation
- Contour erodible slopes were possible to reduce slope gradient
- Promote cover crops in high erosion risk sites and at high risk times
- Minimise the number of cultivations
- Maintain mown grassed headlands which can help filter runoff
- Retain inter-row trash and use minimum tillage planting where suitable

Reduce Drain erosion and maximise sediment trapping:

- Use well designed, shallow, spoon shaped, grassed drains to reduce erosion
- Maintain well grassed drain verges to filter sediment from runoff
- Maintain or restore riparian vegetation on larger drains where erosion is a problem
- Incorporate sediment traps throughout the drainage system

6.2 MINIMISE NUTRIENT MOVEMENT INTO WATERWAYS AND GROUNDWATER

Raised nutrient levels can trigger **excessive** phytoplankton, algae or plant growth. Which can cause depressed DO at night. Subsequent death of these aquatic plants promotes organic matter decomposition which causes further DO decline.

Soil type, slope, soil cover and climate are all on-site factors that influence nutrient loss and movement into waterways. However, some general rules can be applied.

- The first step to minimise nutrient loss is to apply the correct amount of nutrient required by the crop, taking account of present soil fertility. This ensures excessive amounts are not available to be lost.
- Take appropriate soil nutrient tests
- Apply nutrients as required for plant and ratoon crops
- Avoid over-application of any nutrients

- Recommended nutrient rates should not be exceeded, as they already have allowances for potential inefficiencies (losses)
- Adjust application rates when applying other products such as mill mud, biodunder, ash and biosolids

Timing of application is also important.

- Avoid applying fertilisers if the probability of heavy rainfall is high (refer to weather forecasting slides)
- In irrigation areas, avoid heavy irrigation immediately after fertiliser application
- Light rainfall or overhead irrigation (25mm) will help incorporate fertiliser
- Delay fertiliser application until the crop is established and actively growing
- Split applications of nitrogen may be beneficial (despite lack of yield advantages)

Placement of Fertiliser

- Apply urea under the soil surface, or incorporate to avoid volatilisation
- Apply fertiliser in a narrow band in crest of hilled-up row. This keeps fertiliser in the root zone longer and helps prevent leaching and denitrification

Urban, industrial and rural runoff may contain high nutrient loads. High nutrient loads can also occur in areas relatively unaffected by humans. However, the severity of oxygen depletion and the recovery period tend to be less extreme in undisturbed relative to disturbed catchments (Figure 5).

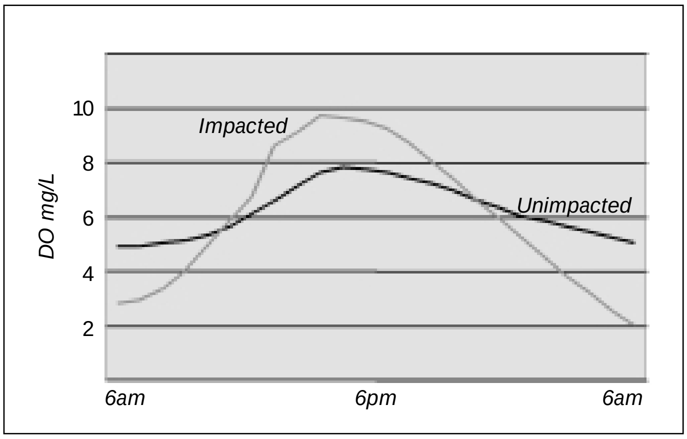


Figure 5. *DO fluctuations are typically more severe in waterways draining disturbed catchments than un-disturbed catchments.*

6.3 MAINTAIN STREAM BANK VEGETATION

RIPARIAN VEGETATION

- *Shade from trees keeps water cool and allows it to hold more oxygen.*
- *Shade from trees helps control the growth of problem weeds such as para grass.*
- *Trees help to extract nutrients from sub-surface flows before entering streams.*
- *Buffers of trees along creeks will help reduce trash & sediment movement into streams.*
- *Trees help prevent bank erosion and subsequent sedimentation.*

Loss of trees along streams allows more light to reach streams. More light promotes growth of weeds which:

1. consume excessive oxygen during cloudy days and overnight
2. provide large amounts of organic matter which decomposes, consuming DO.

Increased sunlight reaching streams also increases water temperatures. Cleared streams are warmer and undergo greater temperature fluctuations. This:

1. reduces the amount of oxygen, able to be retained in water
2. impacts on aquatic organisms that are not tolerant of higher water temperatures

Seek advice from your local revegetation program, Landcare or catchment management group on the best options for revegetating your stream banks. Ask for local native trees that will help shade your stream without interfering with your farming practices.

6.4 MAINTAIN AN EFFICIENT DRAINAGE SYSTEM

Deep drainage systems can prolong the in-flow of low DO groundwater to streams. Groundwater may also contain high concentrations of ferrous irons in areas with acid sulfate soils. This ferrous iron, plus soluble aluminium released at a similar time contribute to COD. Oxidation of the ferrous iron leads to formation of iron floc. This can clog the gills of aquatic organisms and smother submerged plants.

Good surface drainage is essential for cane growing. However, deep drainage may cause problems with DO in streams because groundwater is typically low or devoid of DO.

Maintain drains to a maximum of 1m depth. Stable, spoon-shaped drains are less prone to erosion and are easier to maintain. They are also expected to reduce acid export from acid sulfate soils.

Rock drops and drop boards in drains will help to hold water in drains and will create turbulence for greater aeration *(Figure 6)*.

6.5 REDUCE POTENTIAL FOR HIGH BOD RUNOFF

Agricultural systems can accumulate significant amounts of organic matter. In the case of sugar cane, examples include trash, mill mud, dunder, cane billets and sugar juice. Decomposition of these products under wet field conditions may also generate oxygen-depleted drainage water that, if flushed into creeks, could have a negative impact on DO.

The direct movement of organic matter into drainage systems and waterways may also result in significant BOD loading. The potential for these products to impact on oxygen levels in waterways is currently under investigation.

Drainage and laser levelling increase the rate at which water leaves the paddock. Natural processes that would normally slow the water and allow pollutants to settle or be absorbed are by-passed. This may result in high BOD water entering streams.

To reduce potential for high BOD runoff:

1. Incorporate applications of mill wastes and biosolids immediately where possible
2. Keep drains clean of trash and debris
3. Avoid 'over-drainage'
4. Consider running drainage water through a settling pond or tailwater dam, with sufficient detention time to allow a lowering of BOD
5. Promote aeration by including drops and falls in the drainage system
6. Maintain chopper systems on harvesters to minimise due juice loss during harvesting. Perform cane loss tests and adjust harvester if required to reduce billet loss.

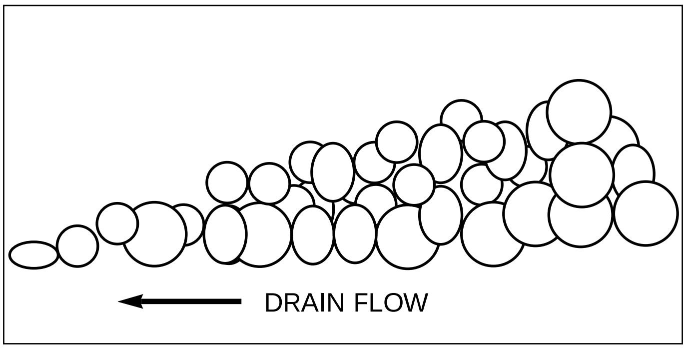


Figure 6. Rock drops along the drainage system will help aerate water.

Contact DNR for advice and permits before doing any works in a watercourse or the Qld Fisheries Service if marine plants are present.

6.6 THE PURPOSE OF SETTLING PONDS/CONSTRUCTED WETLANDS

Agricultural runoff has variable flow rates and pollutant loads, and is highly suitable for treatment by constructed wetlands and settling ponds. Decomposing organisms in artificial wetlands can improve water quality by breaking down excess organic material.

Greater than 90 percent removal of total phosphorus and suspended solids has been recorded in well designed constructed wetlands. The most effective designs include a silt trap, grass filter, wetland, pond, and shallows. Site selection and system size are critical to wetland effectiveness.

Aquatic plants play an important role in these removal processes. Some aquatic plants such as sedges and floating plants, pump atmospheric oxygen into their submerged stems, roots, and tubers. The oxygen is then utilised by microbial decomposers attached to the aquatic plants below water level. This increases the rate of organic matter decomposition.

Plants also play an active role in taking up nitrogen, phosphorus, and other compounds from the water. Some nitrogen and phosphorus goes back into the water as plants die and decompose. In the case of nitrogen, much is converted to nitrogen gas through denitrification processes in the wetland.

Constructed wetlands can also provide high quality wetland habitat for waterfowl, fish and other wildlife. Ponds can also be stocked with molluscs to create an additional biological filter.

The effluent from a well constructed wetland usually has a low BOD but also low DO levels. Aeration is required to raise DO before water is released into a natural system. Drop structures at the wetland outlet are an option (Figure 6).

6.7 MANAGE ACID SULFATE SOILS

Recent CRC Sugar research indicates that significant COD can be present in drainage water from acid sulfate soils (ASS). High levels of iron from jarosite-dominated ASS can result in oxygen depletion through oxidation (Fe^{2+} to Fe^{3+}).

Ferrous iron	**Chemical oxygen demand (mg/L)**			
(mg/L) Oxidised	25% Oxidised	50% Oxidised	75% Oxidised	100%
20	0.72	1.43	2.15	2.86
50	1.79	3.58	5.37	7.16
100	3.58	7.16	10.7	14.3
150	5.37	10.7	16.1	21.5
200	7.16	14.3	21.5	28.6

WHEN MANAGING EXISTING CANELAND ON ASS AREAS:

1. Minimise drainage depth to avoid ASS disturbance
2. Laser levelling and shallow drains may help reduce acid export from ASS
3. When possible, maintain the water table above the unoxidised ASS layer

WHEN CARRYING OUT DRAIN MAINTENANCE IN ASS AREAS:

1. Minimise spoil excavation
2. Treat all drain spoil with appropriate amounts of lime *(a quick field test for predicting lime requirements of ASS affected drain spoil and sediment has been developed by CRC Sugar for NSW canelands)*.

FOR NEW DEVELOPMENTS IN POTENTIAL ASS AREAS

1. Seek advice and/or approvals from your relevant Government Department prior to commencement of work
2. Conduct field tests for ASS in potential risk areas
3. Confirm field tests in the laboratory where a high ASS risk is identified.

Refer to the Code of Practice for Sustainable Cane Growing in Queensland or the NSW Sugar Industry Best Practice Guidelines for Acid Sulfate Soils.

7. WATER QUALITY MONITORING CONTACTS

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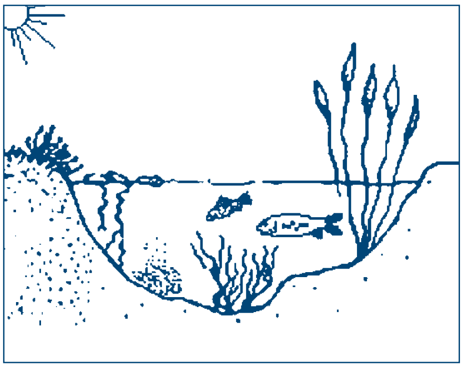
Understanding Dissolved Oxygen in Streams

Good quality fresh water is a vital component of healthy catchments. There is growing community expectation for land and water management to have minimal impacts on water resources. Dissolved oxygen (DO) is an important water quality parameter that influences the living conditions of all aquatic organisms that require oxygen. Urban, industrial and agricultural activities and natural occurrences in catchments can all effect DO in streams and other water bodies. Land and water users can make positive contributions to managing DO.

What is Dissolved Oxygen?

Dissolved oxygen is a measure of the oxygen present in water. It reflects the balance between oxygen use and oxygen production.



What affects Dissolved Oxygen Levels?

Oxygen is dissolved into waterbodies via:

1. Photosynthesis by aquatic plants,
2. The physical transfer of oxygen from the atmosphere to water's surface. Transfer is greatly increased by mixing or turbulence from wind, waves, currents and rapids.

Oxygen is consumed by:

1. Respiration by aquatic plants and animals. The respiration rates of aquatic plants depend mainly on light availability to support photosynthesis.
2. Some chemical reactions (Chemical Oxygen Demand), and
3. Microbial respiration. Microorganisms, such as bacteria, rapidly break decompose available organic matter, consuming oxygen in the process. This has great potential to decrease DO levels. The amount of oxygen consumed by microorganisms to break down a substance is measured as the Biological Oxygen Demand (BOD) of that substance.

Temperature and salinity changes can also influence DO concentrations. Oxygen is more soluble as temperature decreases, hence cooler water can hold more oxygen than warmer water. Higher temperatures also increase the metabolic rate of organisms, resulting in increased consumption of oxygen. Therefore, water temperature can have a significant influence on DO levels, particularly in tropical regions.

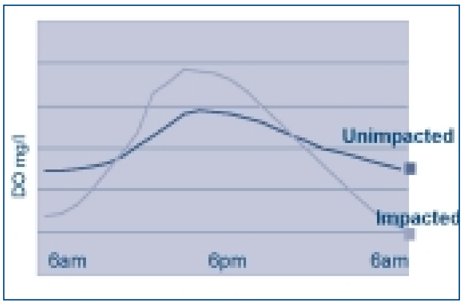
Aquatic plants also impact DO levels. At higher than normal densities most plants can cause DO depletion. Refer to CRC Sugar Fact Sheet: "How do Aquatic Plants Influence DO?" for more information.

Strong diurnal trends in DO levels occur because of the influence of photosynthesis and respiration. Daily highs and lows of DO are known to occur around mid afternoon and early morning respectively. DO fluctuations tend to be more severe in disturbed catchments than un-disturbed catchments.

Why is Dissolved Oxygen Important?

DO Supports Aquatic Life

Many aquatic organisms such as fish,



invertebrates (eg. insect larvae) and microorganisms depend on oxygen dissolved in water for respiration. Without sufficient oxygen, they cannot grow and reproduce effectively. Low oxygen levels cause stress, disease, slow growth rates, and in severe cases, death. The oxygen requirements of freshwater fish and macro-invertebrates differ between species. Different life stages (ie eggs, larvae) of animals may also have different oxygen needs. Research is currently underway to investigate the tolerance of species typically found in coastal lowland streams in cane growing areas.

As a general rule, DO levels below 5 mg/L are stressful to many species. Any long term (chronic) reduction in DO levels can impact on fishery productivity because all organisms play an important role in the food chain.

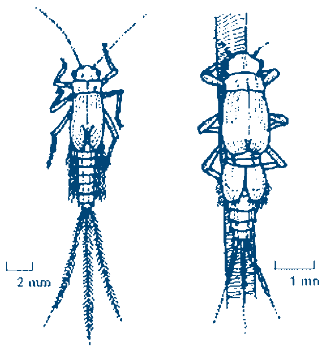
DO Stabilises Aquatic Chemistry

Many chemical reactions involve oxygen. Excessive release of phosphorous and toxins from sediments can occur under low oxygen conditions. Low DO levels also prevent the detoxification of ammonia.

Monitoring DO

DO is relatively easy to measure. Concentrations are commonly reported as milligrams/litre (mg/L) or as a percentage saturation. As DO can change very quickly through a 24 hour period, spot sampling of DO should be routinely done at a similar time of day, preferably around the early morning and mid-afternoon to give an indication of the full fluctuation being experienced in the system. More intensive sampling around runoff events is advisable.

ANZECC Guidelines recommend that DO should not fall below 5 mg/L or 80–90% saturation. This needs to be determined by monitoring over at least one 24 hour period. Macro-invertebrates such as insect larvae are being increasingly recognised as indicators of water quality and can be used for evaluating stream health, including DO.



Managing for DO

Although the effects of land management on DO are poorly understood, landholders can take action to improve the general health of waterways and help prevent or minimise risk of low DO incidents. These include:

- Minimise movement of nutrients, sediment and organic matter (including cane trash, billets and juice) into streams to reduce biological oxygen demand.
- Retain or replant stream bank vegetation to shade out weeds and maintain stable water temperatures. Stream water quality and bank stability are strongly linked to healthy riparian vegetation. Without shade, streams become choked with weeds, erode and silt up. Water temperature and turbidity also increase.
- Maintain efficient drainage systems to minimise ponding in paddocks, but also avoid draining large volumes of low-oxygen groundwater.
- Manage acid sulfate soils to prevent the release to waterways of strongly acid drainage water as this adds to COD, particularly when iron flocs form.
- Help offset increased drainage rates and potential BOD loads by using tailwater dams or settling ponds and delaying irrigation until 4-5 days after harvest.

Many of these actions are important steps to sustainable farming and for farm profitability. They are equally important for maintaining water quality of downstream areas. Refer to CRC Sugar Fact Sheet "How to Help Prevent DO Problems".

For more information, refer to the 'Understanding Dissolved Oxygen in Streams' Information Kit and other CRC Sugar Fact Sheets in this series. Your local Waterwatch Co-ordinator or BSES officer will be able to provide information on water quality monitoring in your local area.

CRC SUGAR

Understanding Dissolved Oxygen in Streams

How Do Aquatic Plants Influence Dissolved Oxygen?

Dissolved Oxygen (DO) is an important water quality parameter. If DO levels in a waterbody drop too low, fish and other organisms will not be able to survive. Different aquatic plants may impact on DO levels in a range of ways.

Submerged aquatic plants

Algae and fully submerged plants transfer oxygen into the water during the day through photosynthesis (the chemical process by which plants fix energy from the sun). During low light conditions (night and cloudy days), these plants consume oxygen through respiration.

Generally, submerged plants contribute about 5 times more oxygen to the water than they consume.

The oxygen contribution of submerged aquatic plants is often virtually equaled by the waterbody's **total** consumption of oxygen by respiration.

As algae usually exist alongside other aquatic plants in waterways, the total biomass of algae can be influenced by the growth of other plants. This has significant implications for DO.

Elevated nutrient levels or other factors may cause algal blooms followed by algal crashes (large scale death). The high BOD of decaying algae depletes DO.

Attached Emergent Plants

When emergent plants are relatively sparse, they provide habitat for the growth of algae that contribute to DO by photosynthesis. However, as emergent plant densities increase, the shading effect blocks light, preventing photosynthesis. Algae are then replaced by microbes, which are nett consumers of oxygen. Therefore at high densities, emergent plants such as paragrass, sedges and reeds can cause significant DO depletion.

Attached emergent plants do not themselves contribute DO to waterbodies as they exchange gas with the atmosphere.

Para Grass and DO

The high biomass and surface area of paragrass can support large populations of microbes, which exert very high oxygen demand.

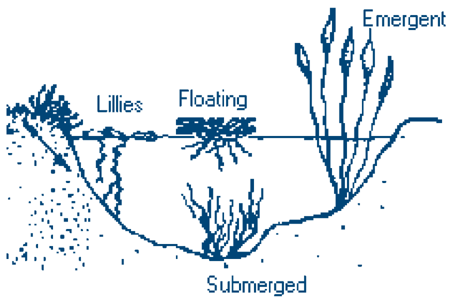
The scrambling habit of Paragrass tends to bind floating vegetation together, preventing its removal during floods. This prolongs the floating vegetation's influence on stream oxygen levels.

Paragrass also traps sediment in streams. If this silt is nutrient rich, the growth of algae, microbes and other plants may be increased.

Floating Aquatic Plants (Macrophytes)

Very low DO levels (below 1% saturation) are common under floating mats of aquatic weeds that completely smother water bodies.

As a floating mass, plants such as water hyacinth, salvinia and water lettuce physically block the transfer of oxygen from the air to the water's surface. These free-floating plants do not directly contribute to DO in water as they exchange gas with the atmosphere, not



the waterbody. Floating plants also block light, prevent photosynthesis by submerged plants. As oxygen consumption continues at depth, DO depletion results. Extensive root systems through the water column provide a large surface area for the growth of microbes, which rapidly use available oxygen. Organic matter shed from the root systems of floating plants further contributes to BOD loads.

Low DO under floating plant mats results in excess release of nutrients from sediments. These nutrients then become available to the floating plants – increasing plant biomass and further depleting DO.

Native Plants and Water Lilies

Native aquatic species such as water lilies tend to be able to occur at relatively high densities without significant adverse impacts on DO. They do not appear to have the same negative impact on DO levels as floating mats of weeds because they are less effective at blocking oxygen transfer from the atmosphere. Water lilies are attached to the bottom and only inhabit certain depths, often preventing them from colonising entire water bodies.

How to Help Prevent Dissolved Oxygen Problems

Dissolved oxygen (DO) in streams is important for the survival of fish and other organisms. Urban, industrial and agricultural activities and natural occurrences in catchments can all effect DO levels. Many aquatic systems are finely balanced and are subject to natural fluctuations. Management practices will not be able to prevent all fish kills. However, good management can help improve the general health of waterways, which may help reduce the severity and frequency of such occurrences. Good farming practices will reduce the potential for adverse impacts of cane growing on DO.

MINIMISE SEDIMENT LOSS

High turbidity reduces photosythesis, causing aquatic plants to consume more oxygen than they produce. In addition, soil loss delivers nutrients to waterways which promote weed growth.

To minimise in-field soil losses:

- green cane trash blanket;
- contour erodible slopes;
- cover crop on fallow lands;
- minimise cultivation;
- minimum tillage plant; and
- maintain grassed, slashed headlands to filter runoff and reduce erosion

Good drain design will reduce erosion and filter run-off. Use shallow, spoon-shaped, grassed drains; maintain well grassed drain verges; maintain or restore vegetation along larger drains and include sediment traps throughout the drainage system.

MINIMISE NUTRIENT LOSSES

Elevated nutrient levels promote weed growth and can lead to algal blooms and crashes, thus indirectly affecting DO. Site specific factors of soil type, slope, soil cover and climate need to be taken into account in any fertiliser program. The following general considerations will help reduce nutrient loss.

Apply only the amount of nutrient required by the crop:

- Soil test
- Apply nutrients at suitable rates for plant and ratoon crops.
- Avoid over-application – note that recommended nutrient rates already have allowances for potential losses.
- Calibrate fertiliser applicator
- Adjust application rates when applying other products such as mill mud, biodunder, ash and biosolids Optimise timing and placement of fertiliser application:
- Apply below the surface where possible;
- If surface applied, delay application until crop is actively growing (~knee high) and use light rainfall or overhead irrigation (25mm) to help incorporate fertiliser;
- Avoid fertiliser application if there is a high risk of heavy rainfall (use weather forecasting);
- Avoid heavy irrigation immediately after fertiliser application;
- Split applications may help reduce losses and can be feasible through trickle irrigation;
- Applying fertiliser in a narrow band in the crest of a hilled up or mounded row keeps fertiliser in the root zone longer and reduces leaching and denitrification

MAINTAIN OR REPLACE STREAM BANK VEGETATION

Shading provided by a good band of stream bank vegetation suppresses weed growth and keeps water temperatures lower. Cooler water holds more oxygen than warmer water. Buffers of trees along creeks *also help extract nutrients from sub-surface flows and help reduce trash movement into streams. Bank erosion and subsequent sedimentation is reduced where a good band of trees exist.*

Seek advice from your local revegetation program, landcare or catchment management group on best options for revegetating and maintaining your stream banks. Ask for native trees that will shade your stream without interfering with your farming practices.

MAINTAIN AN EFFICIENT DRAINAGE SYSTEM

Good surface drainage is essential for cane growing. However, deep drainage may cause problems with DO in streams because groundwater is often low in DO.

Maintain drains to a maximum of 1 metre depth. Stable, spoon-shaped drains are less prone to erosion and are easier to maintain. Rock drops and drop boards in drains will hold water in drains, allowing settling time and also create turbulence for greater aeration of the water.

REDUCE POTENTIAL FOR HIGH BOD RUNOFF

Agricultural systems can accumulate significant amounts of organic matter, including cane trash, billets and juice, mill mud and dunder. As these products break down they consume oxygen, depleting the oxygen level of drainage water. If flushed into creeks, this drainage water could impact on stream DO. The direct movement of organic matter into drainage systems and waterways may also increase oxygen consumption in the waterway.

The impacts, if any, of various farming practices on stream DO are not well understood and are currently under investigation by the CRC Sugar. The following steps will reduce the potential for high BOD runoff:

- Incorporate mill mud/ash and biosolids immediately after application;
- Keep drains clean of trash and debris;
- Avoid direct movement of organic matter into waterways;
- Divert drainage water through a settling pond or tailwater dam, with sufficient detention time to allow lowering of BOD;
- Promote water aeration by including drops and falls in the drainage system.

Contact DNR for advice and permits before doing any works in a watercourse and Qld Fisheries Service where marine plants are present.

MANAGE ACID SULPHATE SOILS (ASS)

Chemical reactions resulting from the high levels of iron exported in drainage from ASS can use up large amounts of dissolved oxygen resulting in very low DO levels.

When managing existing caneland on ASS:

- Minimise drainage depth to avoid disturbing ASS - laser leveling and shallow drains are lower risk methods for achieving drainage needs in ASS areas;
- Regular irrigation may be suitable to maintain the water table above the unoxidised pyritic layer.

When carrying out drain maintenance in ASS areas:

- Maintain drains as shallow as possible and minimise excavation;
- Test for ASS before starting works;
- Treat drain spoil with appropriate amounts of lime where ASS is present;
- Place spoil well away (eg 10m or more) from drain or bund to prevent acid runoff.

For **new development** in potential ASS areas seek advice from BSES, DNR or the relevant state department prior to commencing work. Conduct field tests for ASS in potential risk areas and have laboratory analyses done where ASS risk is identified.

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