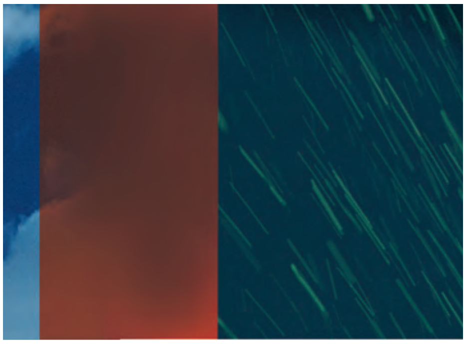

DRAINAGE

Ross Ridge and John Reghenzani

IT is widely thought in Australia that the scarcity of water is the major factor restricting agricultural development. This generalisation holds true for much of the sugarcane production area of Australia, but the opposite, waterlogging caused by poor drainage, can have a significant impact on production in most districts.

The natural drainage capacity of sugarcane soils and ecosystems is a function of climate, local topography and soil parental material. Drainage problems commonly occur where agricultural development has extended into former wetlands, natural drainage is inadequate for prevention of waterlogging, watertables have been raised by clearing of natural vegetation or irrigation, or farming operations have interfered with natural drainage pathways. These situations arise in all canegrowing areas, but drainage problems are more acute in the high-rainfall districts on flood plains.

Successful sugar production in these situations requires improvement of natural drainage to promote better disposal of both surface runoff water and subsurface drainage water. Where drainage is improved, it is important to consider the potential impact on the off-farm environment.

CAUSES OF DRAINAGE PROBLEMS

The most obvious example of drainage problems in the Australian sugar industry is low-lying swamp or flood-plain country in the wetter districts where there are limited natural drainage outlets. In the absence of effective artificial drainage schemes, these areas have persistent high watertables or wetness in the summer wet season over large areas. Typical examples of such extensive drainage problem areas occur in northern New South Wales, Rocky Point, Nambour, Ingham, Tully and Babinda districts.

Similar widespread, but temporary, problems occur in relatively flat land where surface drainage is poor and internal drainage of soils is restricted by either heavy surface soil texture or a clay subsoil. Typically, these areas suffer from temporary perched watertables or general waterlogging during the wet season. The most obvious example of this problem is the Mackay district, where there are extensive areas of duplex soils with clay subsoils of low permeability and areas of heavy clay 'gluepot' soils. Good surface drainage is critical in these areas, and areas of local ponding and waterlogging will occur in any depressions.

In most districts, there are also local wet areas towards the bottom of slopes, due to seepage from the higher areas. The clearing of trees from the upper slopes or irrigation of these areas generally accentuates seepage. Where soils overlie old marine sediments, seepage water is salty and local salt scald areas may develop at the bottom of slopes. Some wet areas also occur at the boundary of freely drained soil and relatively impermeable clay subsoil, rock dykes or other natural impediments to free drainage.

The final major cause of drainage problems is artificial impediments to either surface or subsurface drainage. Among these man-made problems are compacted soil in headlands, roads or mill tramlines across natural drainage channels, filling in of natural drainage lines during farm re-design, and seepage derived from application of excess irrigation water. Within cane fields, surface soil ruts (Figure 1) or smearing created during wet harvests and subsoil compaction by cultivating and harvesting equipment also contribute to drainage problems.

INDICATORS OF POOR DRAINAGE

The most obvious indicator of drainage problems is prolonged soil wetness affecting farm operations. Poor drainage is also expressed in the crop as general yellowing of foliage, poor stooling and gappiness of the stand. In salty seepage areas, cane leaves will appear scorched on the tips and, in severe cases, cane will die out. Waterlogging is particularly detrimental in establishment of plant and ratoon cane, and often results in complete crop failure or very slow germination in wetter sections of cane fields.

Figure 1. *Surface rutting of a cane field due to harvesting when wet.*

In cleared land, prolific growth of weed species typical of wetland, such as sedges and succulents or in salt-affected areas, Rhodes grass or other halophytic species, is a reliable indicator of waterlogging problems. Prior to clearing, the dominance of water-loving species such as *Banksia robur* (swamp banksia) and *Melaleuca* spp. (tea tree) is a clear indicator of wet conditions.

Soil properties can indicate potential drainage problems or reflect a past history of periodic or prolonged waterlogging. Dark-coloured or peaty surface soil, the presence of a bleached layer below the dark surface layer, and subsoil with mottling or dull grey to blue colours indicate varying degrees of historic waterlogging. Where poor drainage is associated with a saline watertable, there is often a crust of salt on the soil surface and a hardpan appearance due to loss of soil structure.

EFFECTS ON CANE GROWTH

Poor aeration is the main cause of depressed growth in waterlogged soils. Root function is adversely affected by the lower oxygen levels and raised carbon dioxide levels, and the root system is shallower (Figure 2). Cane wilts in hot weather because of the reduced capacity of roots to take up water, and use of applied fertiliser is less efficient. In addition, nitrification of soil organic matter is likely to be suppressed and denitrification of nitrate from applied fertiliser increased, resulting in reduced nitrogen uptake by the crop. This is primarily responsible for general yellowing of waterlogged cane. In severe cases of prolonged waterlogging, cane can die (Figure 3).

Temperatures in wet soil are lower due to the high heat capacity of water relative to dry soil components, and waterlogged soils may be up to 4°C cooler than well-drained soil. Consequently, bud germination will be slower in plant and ratoon cane and the risk of stand loss from diseases, such as pineapple disease (*Ceratocystis paradoxa*), is increased.

Chlorotic streak disease is spread by drainage water, and causes significant yield losses in cane if present in wet areas. Losses can be reduced by regular treatment of planting material, but reinfection occurs in poorly drained fields.

The effect of poor drainage on sugarcane yield depends on the combined effect of the above factors on cane growth. In non-saline situations, there is a yield loss of about 0.5 tonnes per day while the watertable is shallower than 500 mm. With a moderately saline watertable, there is an additive effect of high watertables and salinity of the watertable on cane yield.

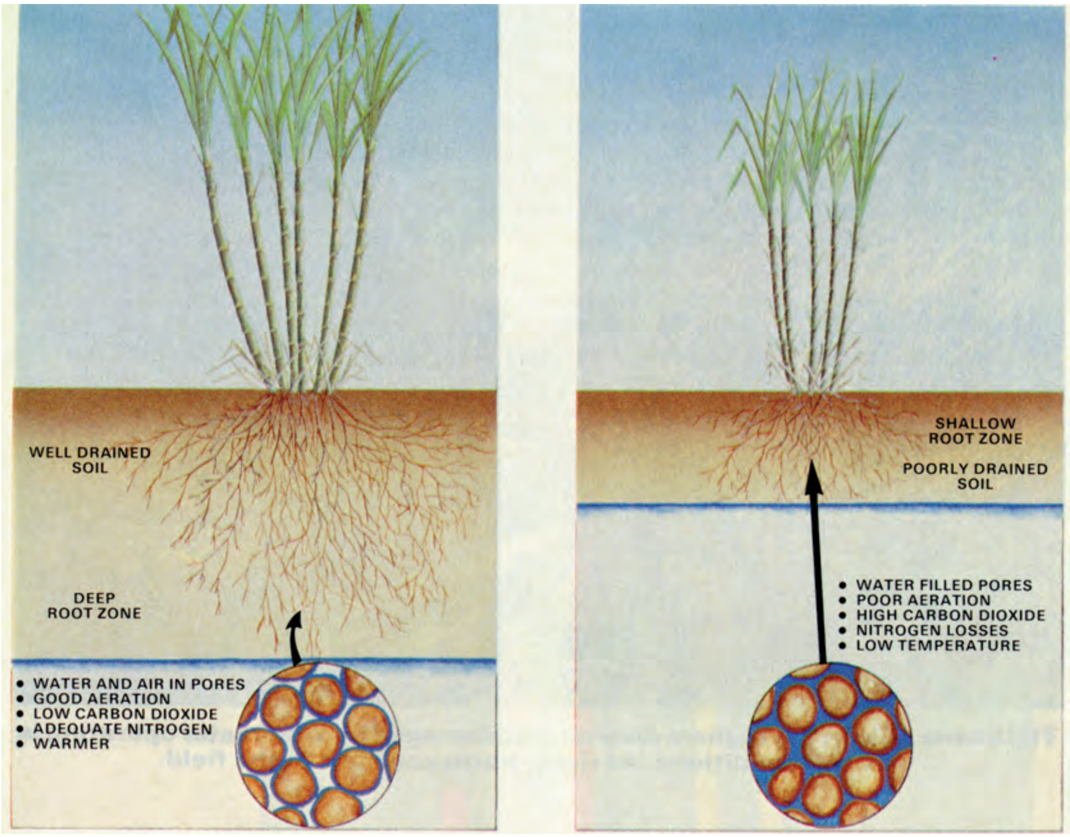

Figure 2. *Comparison of well drained and poorly drained soil.*

Figure 3. *Prolonged waterlogging at the end of the field has completely killed this cane. Note the progression from unthrifty, yellow cane to a healthy crop with improved drainage into the field.*

Poor drainage can also have a significant effect on crop establishment and the detrimental effect appears to be more severe in ratoon cane than in plant cane. In heavy clay soils, furrow irrigation of long rows results in extended periods of waterlogging. This slows germination and reduces vigour of young cane. In practical terms, planting into a mound reduces the impact of waterlogging during furrow irrigation. There are also benefits from mound planting in clay soils under rainfed or spray-irrigation conditions.

Relatively extensive areas of flood plain soils in some districts are also subject to periodic inundation by floodwater (Figure 4). The net effect of flooding on sugarcane yields depends on a number of factors, including age and height of the crop, period of submergence of the growing point, stalk breakage and the silt load in the floodwater. Data from the Mulgrave and Babinda areas in 1977 were used to develop a regression relating yield to stalk height and period of submergence.

Figure 4. *Shallow inundation of mature cane is common in North Queensland and generally results in only a temporary check to cane growth.*

The regression is most accurate for periods of flooding greater than 5 days.

$$\text{Cane loss \%} = -45.46 + 11.13 \times D + 25.45 \times L - 3.95 \times D \times L$$

Where D = Days submerged
L = Stalk length (m).

The regression indicates that cane may suffer around 15–20% yield loss after 5 days of submergence, between 30% and 60% yield loss after 10 days and between 37% and 100% yield loss after 15 days, depending on stalk height within the range 2.5–0.5 m.

BENEFITS OF GOOD DRAINAGE

Apart from the obvious benefit of improved cane yields in well-drained soils, good drainage has a number of indirect effects on farm management.

Rapid drying out of waterlogged soil is particularly important for harvesting operations. Seepage areas or wet sections at the bottom of blocks adjacent to headlands can seriously delay harvesting. Good drainage allows earlier start up of harvesting after wet weather, reduces damage to fields by harvesting and cane transport equipment, and minimises loss of burnt cane when wet weather interrupts harvesting. It will also minimise the risk of leaving standover cane when there is prolonged wet weather during the harvest season.

Good drainage will allow planting at the best time, and it reduces the risk of loss of stand by waterlogging after planting. Shallow inundation can severely damage small plant cane due to the effects of high water temperature or lack of aeration. Similarly, ratooning is slow in waterlogged soils and good drainage can be critical for ratooning of trash-blanketed fields.

Efficient drainage also allows growth of legumes in wetter districts during the fallow period, supplying nitrogen to the plant crop, maintaining soil structure, minimising erosion, and helping in control of weeds and volunteer cane stools. There is a further management benefit through more timely cultivation or herbicide application for weed control. Due to difficult access, weeds often get out of hand in poorly drained blocks and weed competition contributes to overall yield loss. Rat populations and damage to mature cane may also be higher due to a ready supply of high-protein weed seeds.

Many areas now in production in the wetter districts could not have been developed without the installation of major drainage works. Maintenance of an effective drainage system is essential for reliable cane production in these areas.

SURFACE DRAINAGE

All Australian canegrowing districts experience high-intensity summer rainfall and good surface drainage is essential. It is particularly critical in the Mackay and Ingham districts where relatively flat land is combined with duplex soil types at Mackay or heavy textured soil at Ingham, both of which have poor subsurface drainage.

Land planing

Land planing to fill small depressions and to provide a continuous slope of the soil surface is the most effective surface drainage technique. In most canegrowing districts, laser-controlled scrapers and graders are used to flatten blocks to provide more even grades (Figure 5). The precision achieved with this equipment gives effective surface drainage at slopes as low as 0.05%, provided block length is not excessive.

Where less precise control of grades is required, conventional land planes and graders are often adequate for improving surface drainage. For larger cuts and fills, particularly where there is shallow topsoil, bulldozers are often used to remove the topsoil, and the subsoil is levelled with a scraper before the topsoil is replaced. Final grading is carried out with a land plane. This is common practice in furrow-irrigated districts, such as the Burdekin, where there is a risk of exposing toxic sodic clay subsoil during levelling.

Before levelling is carried out, a grid survey should be completed to confirm the direction of slope and determine the most efficient way

Figure 5. *Laser levelling a cane field in the Ingham district.*

of carrying out the cuts and fills required. Computer-based levelling programs are available for calculating cuts and fills. There is also proprietary software for plotting farm or block contours to aid drainage planning. Organisations such as the Bureau of Sugar Experiment Stations, Cane Protection and Productivity Boards and the Department of Natural Resources provide drainage design support for cane farmers. In the Herbert region, in-field design grades of between 0.05% (1 in 2000) and 1% (1 in 100) are used, with the most common being 0.12% (1 in 792). In practice, the determination of slope is based on minimising the amount of soil shifted during laser levelling and limiting the disturbance of natural drainage lines. The average quantity of soil that is moved within the field is 300 m^3/ha.

Land planing is usually combined with shallow, grassed headland waterways to collect runoff water and lead it into either natural drainage channels or deeper open drains. The waterways should have a gradual side slope of 3:1 to 5:1 to allow crossing by harvesters and tractors and ensure stability. There has been some realignment and filling in of natural drainage channels in most districts. Where these also serve as intake areas for underground aquifers, this can reduce the irrigation water supply due to reduced recharge of the underground water supply. This may be the case in the Mackay and Bundaberg districts where excessive draw down of aquifers has caused salt incursion in some areas.

In soils with poor natural drainage, green-cane trash-blanketing will accentuate drainage problems, and generally rows should be shortened to compensate for slower runoff of rainfall or irrigation water. Land planing may also need to be supplemented by hilling up of cane rows in trash-blanketed blocks to improve aeration around the cane plant. Trials in the colder cane producing areas of southern Queensland and northern New South Wales demonstrate a significant yield benefit from hilling up of the cane row in plant cane. This is also the case for poorly drained flood plains that have limited outfall and are so subject to periodic shallow inundation. A large mound formed when filling in can reduce the adverse effects of inundation and waterlogging (Figure 6).

Coulter ripping after harvest is common in trash-blanketed blocks in some north

Figure 6. *Mounding raises the cane stool above the watertable of low-lying areas.*

Queensland districts. This breaks the surface crust after wet-weather harvesting and minimises surface ponding. While this is effective in areas with good natural subsurface drainage, it can be counter-productive in poorly drained soils, as ripping will reduce trafficability in subsequent wet seasons. This is the case in much of the Ingham area, where cane is predominantly cut green.

The practice of forming blocks into narrow beds with shallow water furrows between beds for surface drainage was once widespread in the industry, and is still important in the Nambour area. The bed system is gradually being replaced by precision laser grading of blocks as larger units. The latter practice is more compatible with mechanised harvesting, and is very effective provided there is regular removal of any recurring minor depressions in levelled blocks.

Surface drain design

In-field, cross ditches are used in some districts to connect larger depressions to drainage outlets and minimise earthworks. The ditches are generally kept shallow enough to be crossed by cultivating and harvesting equipment, but they still restrict mechanised operations.

Deep open drains serve a dual function of surface and subsurface drainage in the sugar industry and tend to be used mainly on flat land. They should have sufficient capacity to remove surface water from the crop within a reasonable period of time. As sugarcane can withstand some inundation, drainage capacity can be designed for average rather than peak runoff using the procedure outlined below. The accepted rainfall design intensity for sugarcane in the wet tropics is the 1-in-3-year, 72-h event.

The volume of runoff from a field can be calculated using the formula:

$$V = \frac{KRA}{100} \qquad (1)$$

where

V = volume of runoff (ML),

K = volumetric runoff coefficient, which for most soils varies between 0.6 and 0.7,

R = rainfall in 72 hour period (mm) from Table 1 below,

A = area drained (ha).

Drain capacity is then:

$$Q = \frac{V}{3.6T} \qquad (2)$$

where

Q = drain capacity (m^3/s),

V = volume of runoff (ML) from (1) above,

T = period of inundation (72 hrs).

Design intensities for some centres are presented in Table 1. These data are from records for 1943 to 1987 for all centres except Abergowrie, where records are for 1955 to 1974.

A drainage modulus expressed in terms of litres per second per hectare greatly simplifies the calculation of drain design capacity. These values, which should only be used for flat, sub-catchment areas on the floodplain, have been established for Ingham at 5 L/s/ha and Tully at 10 L/s/ha.

Table 1. Design rainfall intensities for some centres in the wet tropics of Queensland.

Centre	Design rainfall — 1-in-3-year, 72-h rainfall		Mean annual rainfall (mm)
	Total rainfall (mm)	Average intensity (mm/h)	
Mossman	347	4.8	2364
Cairns	346	4.8	2017
Babinda	550	7.6	4164
Innisfail	504	7.0	4007
Tully	537	7.5	4113
Ingham	377	5.2	2094
Abergowrie	290	4.0	1633

The following design criteria are used to determine drain section. The drain must have sufficient capacity to cope with the design discharge. To avoid erosion, water velocity in the drain should not exceed 0.6 m/s for loams and silts and 1.2 m/s for clays and gravels. To prevent siltation, velocity should be greater than 0.3 m/s. Drains with vertical or almost vertical sides are successful on some clay or peat soils, but most drains should have a minimum side slope of 1:1 to prevent collapse of sidewalls and facilitate cleaning. Less stable soils require side slopes of 2:1 to 3:1 and deep open drains are not practical in unstable sands. Both deep and shallow open drains require drop structures in circumstances where following the natural slope of the land will cause erosion.

Velocity is calculated using Manning's equation:

$$v = \frac{r^{2/3}s^{1/2}}{n} \qquad (3)$$

where

v = velocity (m/s),

r = hydraulic radius (m)

$$= \frac{\text{cross section area } (A \text{ m}^2)}{\text{wetting perimeter } (P \text{ m})},$$

s = bed slope (m/m),

n = Manning's roughness coefficient.

The method of calculating cross section area (A) depends on drain shape. The wetted perimeter (P) is that part of the perimeter that gets wet when the drain is full. Manning's roughness coefficient (n) is an estimate of resistance to flow. The value of n for a smooth, regular, unobstructed earth channel with minimal vegetation is 0.025. Medium irregularity, minor obstructions and medium vegetation increase n to 0.065. For most cases, an n value of 0.03 should be used in designs.

Flow rate is calculated using the formula:

$$Q = vA \qquad (4)$$

where

Q = drain capacity (m^3/s), which should be equivalent to Q calculated in (2) above,

v = velocity calculated in (3) above (m/s),

A = cross sectional area used in (3) above (m^2).

Calculation of suitable drain size is an iterative process using formulae 3 and 4 above to estimate the minimum cross-sectional area providing an acceptable water velocity in the drain.

The main disadvantages of deep, open drains are the loss of land in constructing the drains, and the need for expensive crossings for movement of machinery.

The question of how big to make a culvert waterway is easily answered with a simple formula

$$C = \frac{A}{200} \qquad (5)$$

where

C = culvert waterway cross sectional area (m^2),

A = area drained (ha).

Care is needed in disposal of spoil from drains if they are being constructed in areas with acid-sulfate subsoil. The acid-sulfate material becomes extremely acidic on exposure to air. It will be toxic to cane if spread over canefields unless adequate lime is applied. To avoid long-term off-site environmental effects due to toxic concentrations of acidity or aluminium, soil with acid-sulfate potential should remain undisturbed if possible. This may be achieved by finding a new location for the drain if acid-sulfate subsoil along the proposed route is indicated by field peroxide soil tests. Alternatively, shallow drains can be used and steps taken not to lower the watertable excessively.

Regular maintenance of deep open drains is essential, including spraying to control problem weeds such as *Brachiara mutica* (para grass) and regular cleaning with a backhoe or excavator.

SUBSURFACE DRAINAGE

Subsurface drainage is necessary where high watertables occur for a significant part of the cane-growing season. It may take the form of a simple system to drain seepage areas or a whole-farm drainage scheme in low-lying areas. In saline seepage areas or tidal areas, the risk of salinisation has to be taken into account in designing the subsurface system.

Seepage

Seepage may affect only a small area, but this can interfere with operations for one or several fields. In the case of saline seeps, the affected area is likely to expand gradually.

To drain a spring or seepage area effectively, digging of test holes to locate the source of water is useful. An interception pipe or a branched underground pipe system can then be located correctly to remove the seepage water (Figure 7). For saline seeps, pipes generally need to be installed at a depth of 1 m to 2 m, depending on soil texture, to prevent capillary rise of salt water.

Total field drainage

A total field drainage system may be justified in heavy-textured soils, on flat flood plains or in former swamp or tidal areas. The most common method used in sugarcane areas is deep open drains (Figure 8), because of the need to dispose of both runoff and deep drainage water. However, there are examples of extensive subsurface drainage pipe systems in the Nambour, Childers and Burdekin areas.

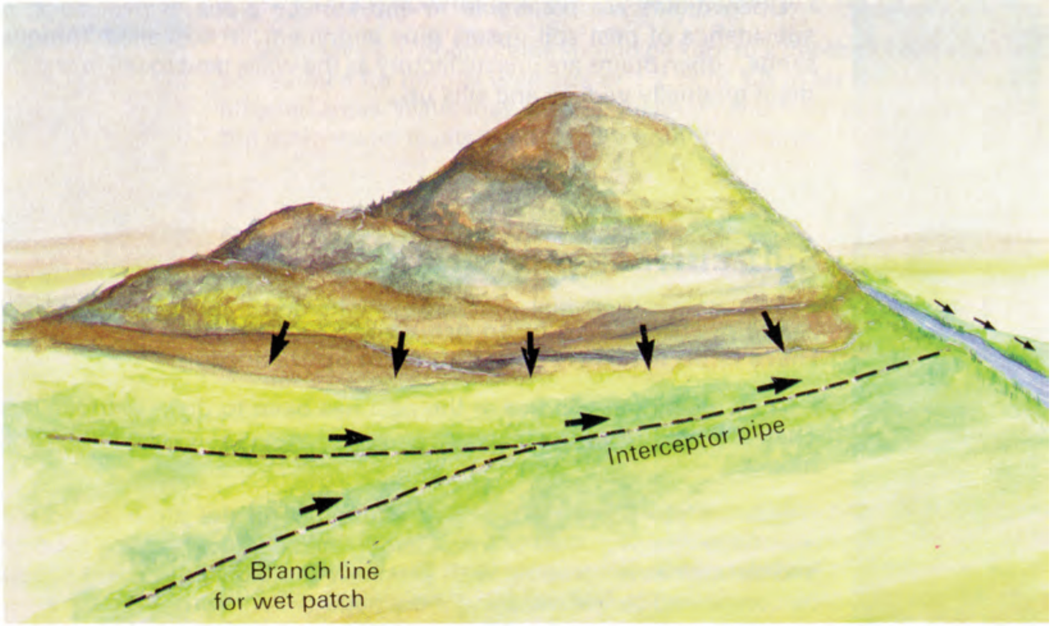

***Figure** 7. Example of seepage drainage system.*

Figure 8. *Deep open drains are only suitable for flat lands and stable soils that do not have an acid sulfate potential.*

Mole drains

In clay soils, mole drains can be used to reduce the cost of subsurface drainage. Soils with a clay content between 30% and 50% are most suitable for mole drainage. The use of moles is unlikely to be successful in sodic and other soils that are prone to slumping and collapse when wet.

Mole drains are formed by pulling a 'torpedo' attached to the end of a thin ripper blade at a depth between 0.5 m and 0.75 m. For best results, a 'plug' or 'expander' should follow the torpedo, expanding and consolidating the channel formed by the torpedo. A torpedo with a diameter of 50 mm gives best results. Larger torpedos are difficult to pull and the mole drains are more prone to collapse.

Most mole drains in the sugar industry are installed by starting at an open drain and drawing uphill away from the drain, but mole drains can also be drawn into the sand envelope above subsurface drainage pipes. Mole drains can provide drainage through the headland barrier and reduce ponding at the lower end of blocks.

The maximum recommended length of mole drains is 200 m, but longer mole drains can be effective if there is adequate slope (above 0.1%) and a stable soil. Common spacings range from 1.5 m (every interspace) to 7.5 m, the closer spacings allowing for failure of a proportion of the mole drains. It is usually necessary to reinstall mole drains each crop cycle.

Subsurface drainage pipe

The most common application of subsurface drainage pipes in the sugar industry is for draining seepage areas, and there are few examples of whole-block drainage. Clay pipes were used in the oldest systems, but new installations are mainly corrugated, slotted plastic pipe due to its ease of installation and competitive costs. The most commonly used pipes are 100 mm in diameter and systems are designed to dispose of 5–8 mm of water per day. Pipe capacity at different slopes are given in Table 2. If the area serviced by the pipe exceeds the drainable area listed in Table 2, a larger pipe diameter is required. It may be less expensive and more practical to use two, 100 mm pipes in some situations. Typically, pipe is installed at a minimum slope of 0.1%, but a slope greater than 0.2% is desirable to ensure that there is self-cleaning of silt from the pipes.

Table 2. Drainage capacity of commonly used 100 mm corrugated plastic drainage pipe versus pipe slope.

Slope %	Capacity m^3/day	Drainage required mm/day	Drainable area at 75% efficiency (ha)
0.1	230	5	3
		6	2.5
		8	2
0.2	310	5	4.2
		6	3.5
		8	2.7
0.5	500	5	6.7
		6	5.6
		8	4.2

The spacing of drainage pipes depends on soil hydraulic conductivity (rate of water flow through the subsoil), pipe depth, amount of water to be drained per day and the depth of any impermeable layer. Generalised pipe spacings for different estimated daily drainage requirements in Queensland sugar growing districts are given in Table 3. Actual hydraulic conductivity measurements are required for accurate design of individual farm subsurface drainage schemes.

Typically, trenching is carried out with a backhoe or excavator, but chain trench diggers are generally faster and less expensive if pipe can be installed in relatively dry conditions. Pipe should be installed on a 50–100 mm bed of coarse sand or graded aggregate (3–10 mm) and covered with an additional 200 mm of this filter material. A deeper cover should be used if mole drains are to be drawn through the filter material. The depth of pipe installation is usually dependent on available slope to the outlet, but in general should be at least 1 m in non-saline areas or 1.5 m in saline seeps. The aim is to keep the watertable below 0.5 m and 1 m, respectively.

Specialised equipment to reduce the costs of laying subsurface pipe is available in some districts. This includes tractor-drawn injection tines with a hopper for placing gravel around the pipe as it is laid, and a hopper which can be placed in the backhoe trench to feed gravel around the corrugated pipe as the trench is dug (Figure 9). The hopper is pulled along in the trench by the backhoe. The latter system is more versatile as it can be used for a range of trench depths. In some cases where there is no outlet for underground pipes, a sump is constructed and a pump is used to lift water to the surface for disposal.

High-pressure drain cleaners are now available in most districts, and a system of Y pieces installed every 100 m with a 100 mm diameter branch to the soil surface facilitates insertion of the drain-cleaning nozzle. The outlet is protected with a short length of concrete pipe. Cleaning should commence at the outlet and work upslope using clean water in a spray tank to avoid damage to the high-pressure pump.

DRAINAGE IN FLOOD PRONE AND TIDAL AREAS

Protection of cane in low lying areas from inundation by tidal or flood waters is a prerequisite to successful drainage. This is achieved in many situations in the sugar industry by a combination of levy banks and floodgates. A properly constructed levee bank and floodgate system prevents entry of tidal and flood water into farms and allows water to flow out at low tide or when floodwater recedes. Much of the northern New South Wales sugar producing area is protected by floodgates and levees supplemented by low lift, high capacity pumps to give more rapid removal of floodwater. Axial flow or propeller type pumps give high output and pumping efficiency at low heads and these are usually powered by a tractor PTO system.

Table 3. Pipe spacings (metres) for different soil hydraulic conductivity values and amounts of seepage water (pipes at 1 m depth).

Soil hydraulic conductivity (K) (m/day)	Pipe spacing (m)		
	Babinda-Tully 8 mm/day	Nambour-Mackay 6 mm/day	Ingham-Bundaberg 5 mm/day
Heavy clay (0.1–0.25)	6–11	7–13	8–15
Clay loam (1.0)	29	34	39
Loam (2.5)	51	61	68
Sand (5)	77	92	101

* soil type K values are a guide only.

Figure 9. *Gravel hopper in an excavated trench for placing a gravel envelope around corrugated drainage pipe.*

In tidal areas, floodgates act to minimise salt entry into caneland while allowing leaching of salt from reclaimed land within the levee. Examples of sugar producing areas reclaimed in this manner include sections of the Rocky Point Mill area, Nambour area and Fairymead Plantation at Bundaberg.

COMMUNITY DRAINAGE

In sections of most districts, drainage is poor because of the lack of suitable outlets for drainage water from individual farms. Provision of outlet drains may involve cooperation between several growers and this is best achieved by establishment of a statutory drainage board. There are a number of examples of successful community drainage schemes in the sugar industry. Computer-modelling tools currently under development will result in improved integrated drainage designs which optimise scheme performance and crop productivity, while minimising adverse environmental effects.

A statutory board is able to acquire easements for main drains, raise loans and obtain government financial assistance. It also has the power to negotiate with local authorities. All growers who benefit from a scheme contribute levies, usually based on the degree of benefit, and the board is responsible for maintenance of drains on a permanent basis.

ENVIRONMENTAL ISSUES

Drainage of caneland can have a significant impact on the environment and there are several issues that canegrowers need to recognise in installing and managing drainage schemes. These include regulations concerning the clearing of mangroves in tidal areas, the potential for acid export from acid sulfate soils following drainage and aeration of drainage spoil, and the potential for fertiliser, herbicide, insecticide and other contamination of drainage water.

There are industry recommendations in the form of Codes of Practice to minimise the risk of environmental impact from drainage systems. Many modern drainage schemes include design structures such as silt traps to retain soil on the farm, rock baffles which aerate low oxygen waters to improve fish survival, and culvert design to reduce water velocity and aid fish passage. Large drainage lines may include revegetation schemes that reduce the incursion of exotic weeds and improve the fish habitat. Clearing of trees from natural drainage lines and riverbanks to establish drainage works is limited by regulations. These are outlined in the chapter Environmental Management.

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