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A SURVEY OF THE FREQUENCY, DURATION AND OXYGEN CONTENT OF SURFACE AND SUB-SURFACE WATER IN REHABILITATED MINED AREAS AT HUNTLY MINE

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SUMMARY

Surface ponding of water is evident in many recently (0 – 3 years old) rehabilitated minepits; this occurs at the bottom of the pit but also in riplines on the upper slopes of the pit. The presence of surface and sub-surface ponds has the potential to affect plant growth and survival. The aims of this project were to monitor the duration and frequency of ponding, and to monitor oxygen levels to assess the potential for waterlogging to occur.

Observations at the Huntly mine found that ponding is highly variable within and between rehabilitated minepits. Level floats attached to data loggers in six rehabilitated minepits were used to determine the duration and frequency of surface ponding. Between September and May 1997 depressions held water between 5 and 25% of the time. The average duration of ponding each week was highly correlated to the weekly rainfall. We believe that surface ponding can be caused by three circumstances: (i) clay collecting in depressions, (ii) low infiltration capacity of a sub-surface clay layer or (iii) a surface expression of sub-surface accumulation of water.

Seven minepits with obvious areas of ponding were selected for monitoring of the depth of sub-surface ponding and oxygen content of the water. Piezometers were placed in 78 ponds at depths of 30, 60 and up to 90 cm. There were five types of surface ponds and profiles identified; (a) fast draining ponds with little impediment to water movement through the soil, (b) slowly draining ponds with some impediment to water movement through the soil, (c) ponds that drained into a sub-surface pond that prevented water movement, (d) ponds that were actually drainage sumps formed in low lying areas of the pits and (e) ponds overlying a sub-surface water channel. About 30% of the ponds were of type (c) and (d), and were associated with sub-surface water that had a low oxygen concentration.

Thus, the potential exists in early vegetation rehabilitation for surface ponding to be associated with sub-surface ponding or waterlogging. The low oxygen content of sub-surface water would have detrimental effects on plant growth. *Eucalyptus marginata* is the main tree species used to revegetate the minepits. However, the collars of *E. marginata* seedlings are very susceptible to infection by *Phytophthora cinnamomi* and surface ponding provides ideal conditions for infection. Consequently, the combination of surface ponds and sub-surface waterlogging would be expected to result in increased disease severity.

INTRODUCTION

Bauxite mining is a major land use of the jarrah (*Eucalyptus marginata)* forest, south-east of Perth, Western Australia. Mining occurs in areas of the forest where soils infested with the pathogen *Phytophthora cinnamomi* are common. *P. cinnamomi* is the cause of the disease known as 'jarrah dieback' which can kill *E. marginata* and up to 40% of understorey species (Shearer and Tippett 1989). The rehabilitated areas are revegetated solely with local species including *E. marginata*. The survival of *E. marginata* in rehabilitated mined areas is high (Colquhoun and Petersen 1994) but there are localised areas where *E. marginata* deaths caused *by P. cinnamomi* are evident (Hardy *et al*.1996). These areas of higher mortality appear to be associated with surface ponds of water.

During mining the topsoil and underlying gravel is removed and the lateritic layer (usually 3 – 6 m) is mined. The floor of the minepit consists of low grade bauxitic materials and kaolinitic clays. The rehabilitation process involves landscaping the minepit floor and pit faces to blend the topography of the rehabilitated pit with the surrounding forest. Following landscaping, the gravel and topsoil are returned and the area is ripped on the contour to a depth of 1.2 m (Ward *et al.*, 1996). Ripping produces a series of undulations (called riplines, see Figure 1) which serve to improve infiltration of water and decrease the risk of erosion. Ripping also brings patches of kaolinitic clay close to the surface. Clay particles have the potential to wash into the bottom of the riplines and impede infiltration. In the natural forest a sub-surface clay layer has been found to impede infiltration resulting in transient sub-surface ponding of water (Kinal*et al.*, 1993). It is not known if water accumulates on this clay layer in the rehabilitated mined areas. Sub-surface water accumulation has the potential to affect plant growth and increase the risk of infection by*P. cinnamomi.*

Observations of 1-7 year old *E. marginata* growing in rehabilitated bauxite minepits indicated that *P. cinnamomi* only formed lesions in the collars (Hardy *et al.* 1996). Plants with lesions were invariably found in the riplines and they hypothesised that the invasion of the collar by *P. cinnamomi* was associated with the ponding of water around the plants for hours or days following rain (Figure 1). This is interesting as it has generally been assumed that *P. cinnamomi* is a root pathogen of *E. marginata.* O'Gara *et al.* (1996) then demonstrated that zoospores of *P. cinnamomi* can enter, infect and form lesions through unwounded periderm tissue of *E. marginata* growing in these areas.

Waterlogging is thought to predispose *E. marginata* to infection by *P. cinnamomi* (Davison, 1994; Davison and Tay, 1987; Zentmyer, 1980) probably as a consequence of the negative effects that low oxygen levels have on plant growth, development and disease resistance (Drew and Lynch, 1980; Kozlowski, 1984). In rehabilitated minepits the potential exists for an interaction between surface ponding

The aim of this study was to determine the duration and frequency of surface ponding and investigates the association between surface ponding and sub-surface waterlogging in recently rehabilitated minepits (1-3 years).

METHODS

Measurement of surface ponding

Level floats (model 339-730 RS Components Ltd.) were used to determine when water was present in a ripline or other depression. The floats were secured between two aluminium prongs attached at 110° to an aluminium base. Six sites were selected in 1-2 year old rehabilitated vegetation at Huntly mine based upon the presence of surface ponding. These were monitored between May and September 1997. There were three sites at Leena Rd, two at Banya Rd and one at Yallara Rd. Each data logger had six floats attached to it via 10 m of insulated cable. The data loggers were placed centrally in an area where six ponds (each covering an area of at least 1 m^2) were located. The floats were placed at the deepest point of the depressions and a rock put on the aluminium base to secure it. The data loggers were configured to record a higher current when the float was in the open position, i.e. when water was present. Floats did not switch on until there was 1 cm of water in the depression. The floats were set in place during rain when all the depressions selected contained at least 4 cm of water. The presence of water was recorded hourly. A recording rainfall gauge was also attached to the data logger at Yallara Rd. Data were downloaded from the data loggers every 2-3 weeks.

Figure 1. Surface ponding in the riplines of a recently rehabilitated minepit.

Depth and oxygen content of sub-surface water

The depth and oxygen content of sub-surface water was measured in 1-3 year old rehabilitated minepits at seven sites at Huntly mine between June and September 1997. There were three sites with 1, 2 and 3 year old rehabilitation at Leena Rd (F4419), two sites with 1 and 3 year old rehabilitation at Wuka Rd, one site with 1 year old rehabilitation at Banya Rd and one site with 2 year old rehabilitation at Yallara Rd. The extent of ponding is variable between and within rehabilitated minepits. This study targeted areas where surface ponding was common. Ponding was not generally observed in rehabilitated vegetation over 3 years old (Hardy, pers. comm.). At each site, groups of three piezometers were inserted in each of twelve ponds or depressions at different elevations across the site. The piezometers were 3 cm diameter steel tubes, up to 1.5 m in length that were cut and tapered at the base to form a spear. Slits were made at 3 cm intervals in the basal 25 cm of the piezometer. Piezometers were inserted to depths of 30, 60 and up to 90 cm using a sledgehammer. Piezometers could always be inserted to 60 cm, but there was often a hard clay layer between 65 and 90 cm. Piezometers could only be forced a few centimetres into this layer.

Piezometers were inserted at least one day before any measurements were made. On the morning of measurement, the depth of water was determined by putting a dowel rod down each piezometer. If water was present it was recovered by inserting a silicon tube down the piezometer and sucking out the water. The water was transferred from the tube into a plastic vial and the oxygen content of the water determined using a dissolved oxygen meter. This process was repeated in the same afternoon. Any piezometers that contained water in the afternoon were left in the ground. The rest were removed and another site set up for measuring. This process was repeated for seven sites. The piezometers that were left in the ground were monitored on a regular basis. Piezometers were not examined if it had been more than two days since the last rain.

The ideal way to measure the oxygen concentration of water is in a nitrogen atmosphere. Davison and Tay (1991) described a method in which aquarium stones attached to polythene tubes were buried in the soil. A three way tap, fitted into the end of each tube, allowed for the water to be sucked out without coming in contact with air. However, in our study we were looking for a rapid procedure that allowed us to measure both the depth of water and the oxygen concentration of that water in many piezometers. The water in the piezometers was in contact with air and there would have been some mixing with the air giving artificially high readings. Although there would have been some increase to the oxygen concentration during sampling we believe that it would not affect the overall results. Even with artificially increased oxygen concentrations we did measure concentrations of less than 30%.

RESULTS

Frequency of pond formation

The use of level floats proved to be an accurate and efficient way to measure the presence of water in depressions (of the 36 floats placed in the field, 35 provided regular information). Sometimes a small pebble or mud prevented a float closing; data from these floats were excluded from analysis for the period of the fault. There was no significant difference ($P<0.05$) between sites in the duration of ponding. Thus data from all 35 floats were pooled for comparison.

As expected, ponds formed in depressions following rain (Figure 1). The greater the intensity and the duration of the rainfall events, the greater the percentage of depressions that ponded. Most ponds emptied soon after rain, but in periods of continual rain, ponds held water for up to 13 days (Figure 2). This is illustrated more clearly by breaking the data down into weekly averages (Figure 3). Between June 21 and July 4, only 0.8 cm of rain fell and no ponding occurred. Over 7 cm of rain fell between July 5 and July 11, however, as it had not rained in the previous two weeks, the ground was very dry and ponds took a long time to form and they drained rapidly. In comparison, between May 31 and June 6 over 10 cm of rain fell and it had rained in the previous week; all of the depressions ponded for at least 10% of the week, whilst 15% of the depressions ponded for the whole week. Overall, the average duration of ponding each week was highly correlated to the weekly rainfall ($r^2 = 0.82$).

Over the whole monitoring period (May-September 1997), three depressions only ponded for less than 5% of the time whilst two others ponded for over 35% of the time (Figure 4). The majority of depressions ponded for between 15 and 25% of the time. The depressions that ponded for only a short time required more rain to fill and they drained quickly, often within an hour of rain. Other depressions held water for several days following rain. There was no relationship between the depth or volume of the depression and the time that it ponded ($r^2= 0189$ and 0.214 respectively). The duration of ponding was probably related to the depth of the clay film that accumulated in the depression. This was not measured, but it was commonly observed that piercing this film caused most ponds to drain immediately.

Depth and oxygen content of sub-surface water

The data from a 3 year old site at Wuka Road have been excluded from the comparisons because no water was found in the piezometer throughout the monitoring period. The trees at this site were very large compared with the other sites. The lack of water in the piezometer may be due, in part, to higher rates of water use and rainfall interception by the vegetation, but may also reflect higher

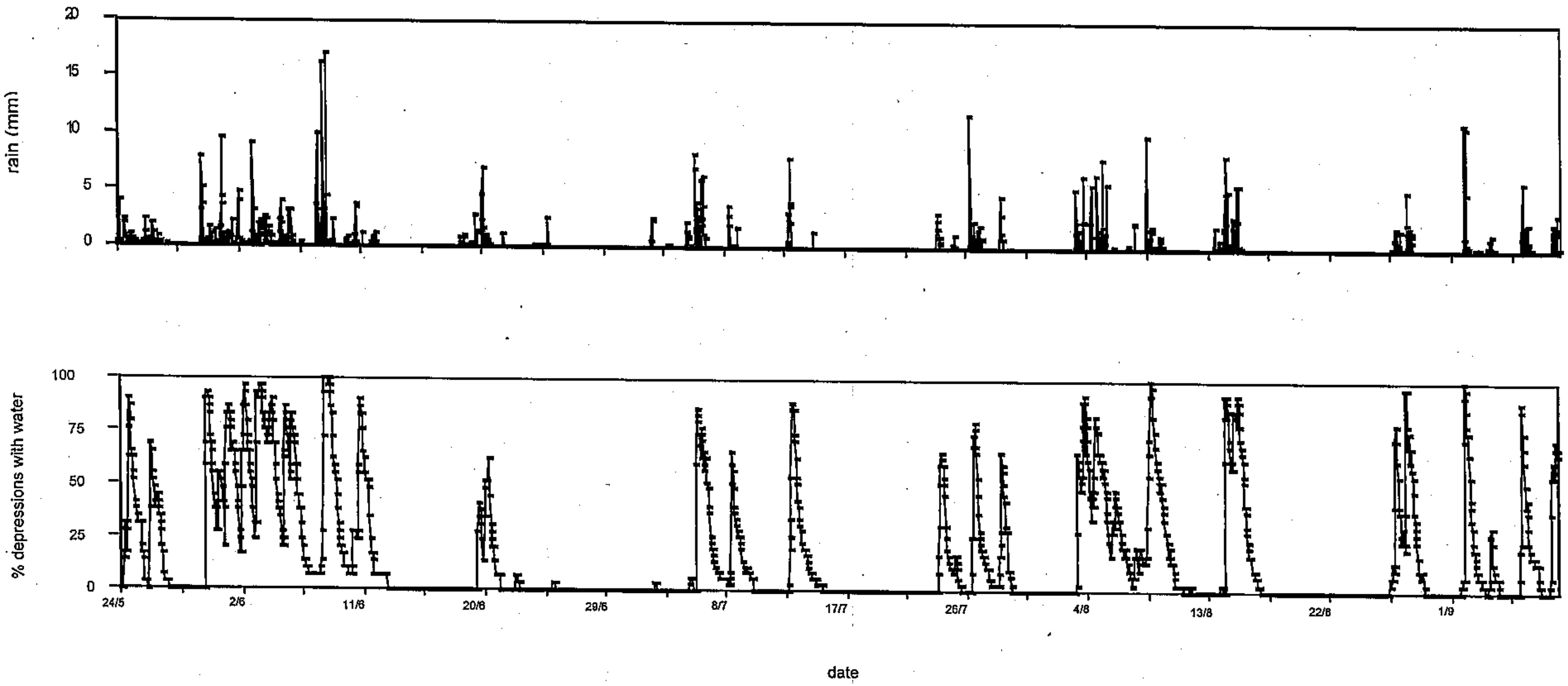

Figure 2. Rainfall (mm) and the proportion of depressions ponding (%) recorded hourly between 24/5/97 and 9/9/97 at Huntly minesite.

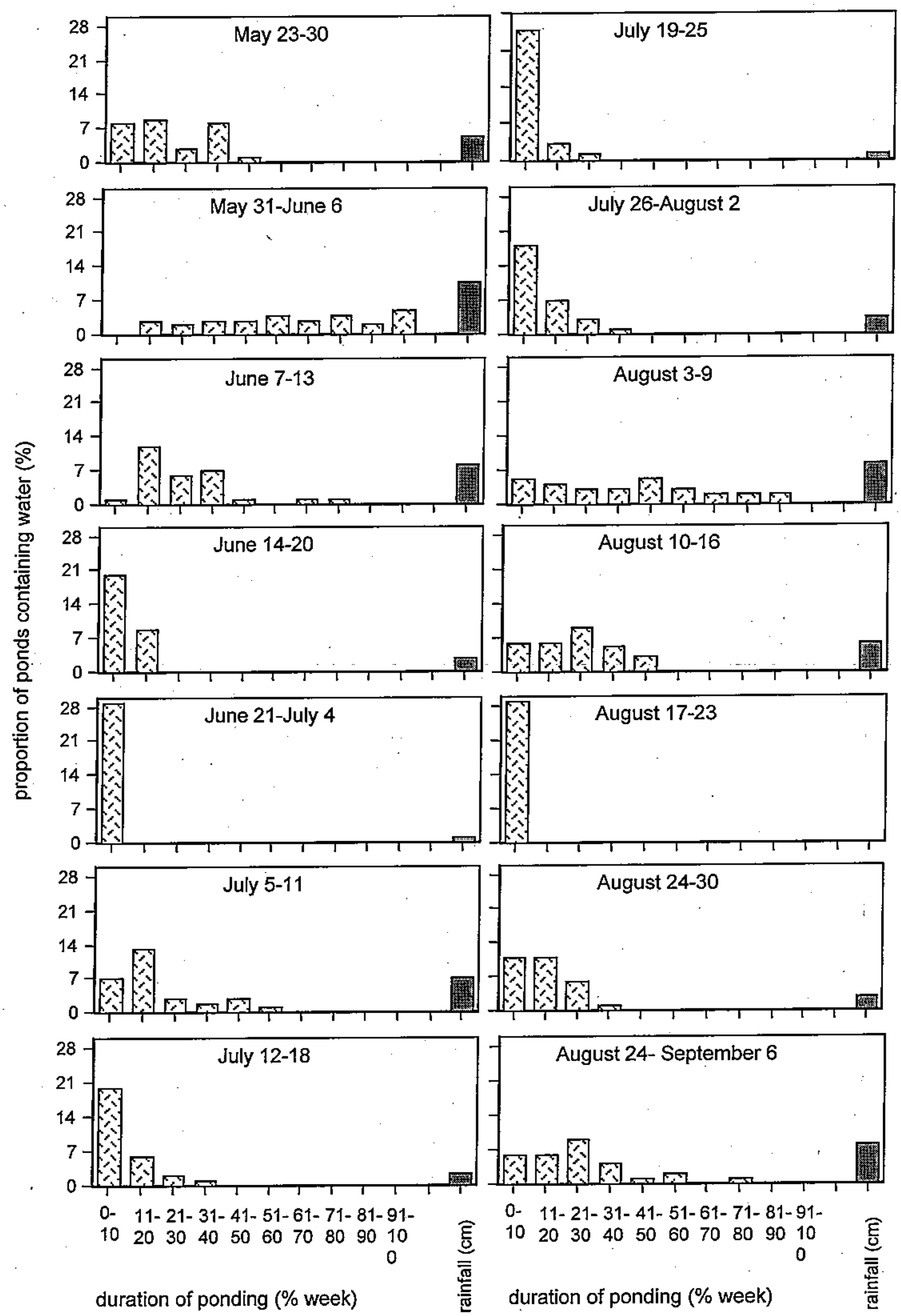

Figure 3. The average duration that each depressions ponded on a weekly basis. i.e. Between July 5 and 11, 14% of the depressions ponded for 11-20% of the week. The total weekly rainfall (cm) is given on the same scale.

infiltration rates caused by the presence of large roots. In comparison, the 3 year old site at Leena Rd yielded a lot of water. At this site there was a hard clay layer 65-85 cm below the surface at the base of and about 40 m up a 20-30° slope. Water was collected from piezometers at all the other sites. When water was collected from surface ponds it was always fully aerated. We identified five types of surface ponds and profiles (Figure 5):-

(a) fast draining ponds with minimal impediment to water movement through the soil,

(b) slowly draining ponds with some impediment to water movement through the soil,

(c) ponds that drained into a sub-surface pond that prevented water movement,

(d) ponds that were actually drainage sumps formed in low lying areas of the pits,

(e) ponds overlying a sub-surface water channel.

Half of the ponds examined were of the first type; fast draining ponds with little impediment to waterflow (Table 1). Only one pond overlaid a water channel. The remainder was divided approximately equally between the other three types. There was no correlation between site or vegetation age and pond type.

Fast draining ponds were transient and the profile provided little impediment to water flow and water drained through the profile within a few hours of rain. Following rain, water was first found in the surface pond and at 30 cm, a few hours later water was only found at 60 or 90 cm. The day after rain, around 10 cm of water was collected at each depth (Figure 6a). The oxygen content of this water did not vary as it moved through the profile remaining on average at about 50% the oxygen content of air (Figure 6b). Once the water was removed from the piezometer it did not refill unless there was more rain. These piezometers were removed from fast draining ponds after one day of measurements.

Slow draining ponds generally had a thicker clay base to the surface pond and a hard clay layer at a depth between 65 and 80 cm. Water moved more slowly down the profile, however when it reached the clay layer it was not trapped and continued to drain. Drainage of these profiles was complete 2-3 days following rain. Between 15 and 20 cm of water was sampled at each depth (Figure 6a). The oxygen content was similar to that of fast draining ponds, remaining at 50% the oxygen content of air through the profile (Figure 6b).

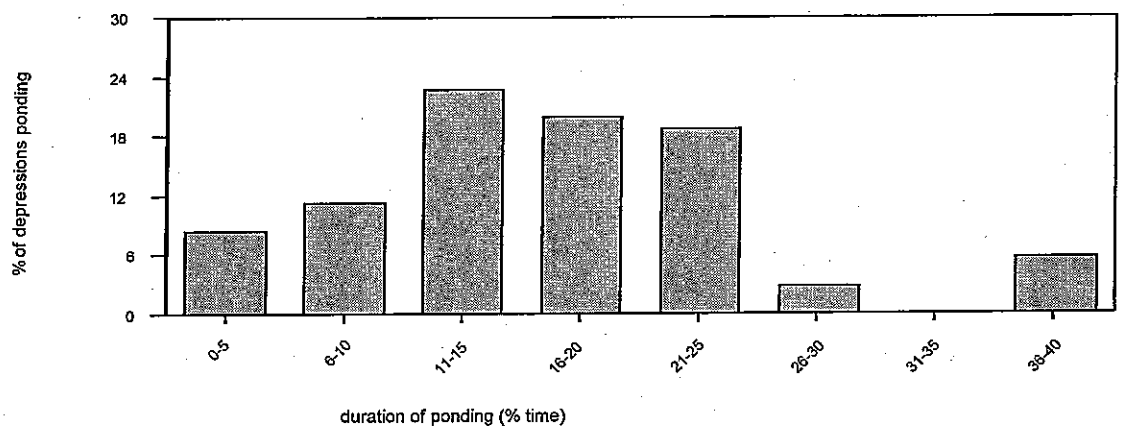

Figure 4. The average duration of ponding over the time course of the survey (23 May - 7 September 1997). During this period the total rainfall was 67 cm.

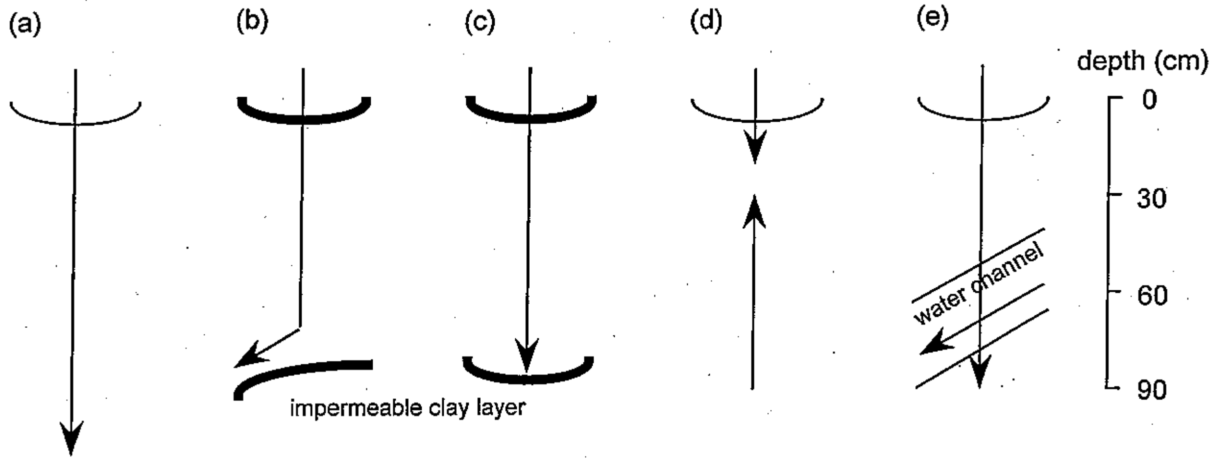

Figure 5. Types of ponds identified from the survey of recently rehabilitated pits at Huntly mine. (a), (b) and (e) water moves through the profile. (c) depressions in the impermeable clay layer trap water. (d) a sump with water rising up the profile.

Table 1. The number of ponds of each type found at each site. The age of the rehabilitated vegetation is given in years (YO = year old)

site	fast draining	slow draining	sub-surface pond	sump	water channel
Leena Rd (1 YO)	1	6	4	3	0
Leena Rd (2 YO)	9	0	5	0	0
Leena Rd (3 YO)	2	1	1	6	0
Wuka Rd (1 YO)	9	4	0	0	0
Banya Rd (1 YO)	11	0	3	0	0
Yallara Rd (2 YO)	8	o	2	2	1
	40	11	15	11	1

The third type of pond was similar to that of the slowly draining ponds except that the clay layer somehow trapped water lower in the profile. There was probably a sub-surface depression where water collected. In these profiles, about 30 cm of water was regularly sampled from the deepest piezometer, indicating that water was trapped (Figure 6a). If all the water was removed from this piezometer it would refill in a few hours. The oxygen content of this water collected at 90 cm was below 30% the content of air (Figure 6b). This was the lowest oxygen content of all the water collected.

All the pits examined had been contoured so that water collected in sumps in low lying areas of the pits. These areas appeared to be ponding, but often there was so much water in the profile that the ponds were filling from below. In these ponds, an average over 40 cm of water was collected from the 60 and 90 cm piezometers (Figure 6a). In some cases over 60 cm of water was collected. This indicated that the soil profile was filling with water from below. The oxygen content of this water was higher than that for trapped water, probably because it was being constantly recharged (Figure 6b). However, there were no oxygen readings made later than 2 days after rain; the oxygen content probably dropped when the sump stopped being recharged.

One piezometer was placed in a water channel. This was evident because it did not matter how much water was removed, it always stayed at 40 cm and the oxygen content of this water was high at 70% air (Fig 6ab). We envisage this channel as a sub-surface depression where water ponds; this pond is being constantly refilled from the surrounding area and constantly emptied by lateral flow i.e. analogous to an overflowing bath with water continuing to flow from the taps.

DISCUSSION

This survey of recently rehabilitated bauxite minepits has demonstrated that whilst ponds form, the duration of ponding varies considerably, as does the types of ponds that form. Between May and September 1997, some depressions ponded for less than 5% of the time whilst others ponded for over 35% of the time. The depressions that ponded for a short time only held water while it rained and drained quickly, often within an hour of rain. Other depressions, particularly those with a deep clay base, held water for several days following rain. It is believed that ponds only formed in rehabilitated minepits with vegetation less than four years old (J. Koch and I. Colquhoun pers. comm.). After this period the tree root systems are probably large enough to take up some of the free water. Interception of rainfall by the vegetation would also decrease the volume of water reaching the soil and infiltration may have increased with the presence of large roots. It should be noted that the rainfall in the winter of 1997 was below average. In an average year, rain would be expected more often and for longer periods. Thus, ponding would be more common with even the most transient of ponds lasting longer. The frequency of ponding varied between rehabilitated minepits and ponding was not uniform across individual sites. Our observations indicated that the frequency and positioning of ponds was not dependent upon surface topography; ponds formed at all elevations of the slope as well as in the sump area.

The monitoring of sub-surface water levels at seven sites also indicated that the majority of ponds drained within hours of rain, showing minimal impedance of water movement through the profile. However, around 30 % of the ponds examined were associated with some sort of sub-surface ponding during the winter months. One pond was above a water channel where water was moving quickly towards the sump and had a relatively high oxygen content. Around 15% of ponds were associated with sub-surface water that was trapped, probably by a depression in the clay layer 70-90 cm down the profile. Within 2 days of rain, the oxygen content of this water was less than 30% of the oxygen content of air. This would probably decrease with time after rain. Similarly, ponds filling from drainage sumps had reasonably high oxygen contents soon after rain, but when the sumps stopped being recharged then the oxygen level of the water should also decrease. Observations of sumps in late spring indicated that many still held water and that this water had a strong hydrogen sulphide smell, indicative of anaerobic conditions.

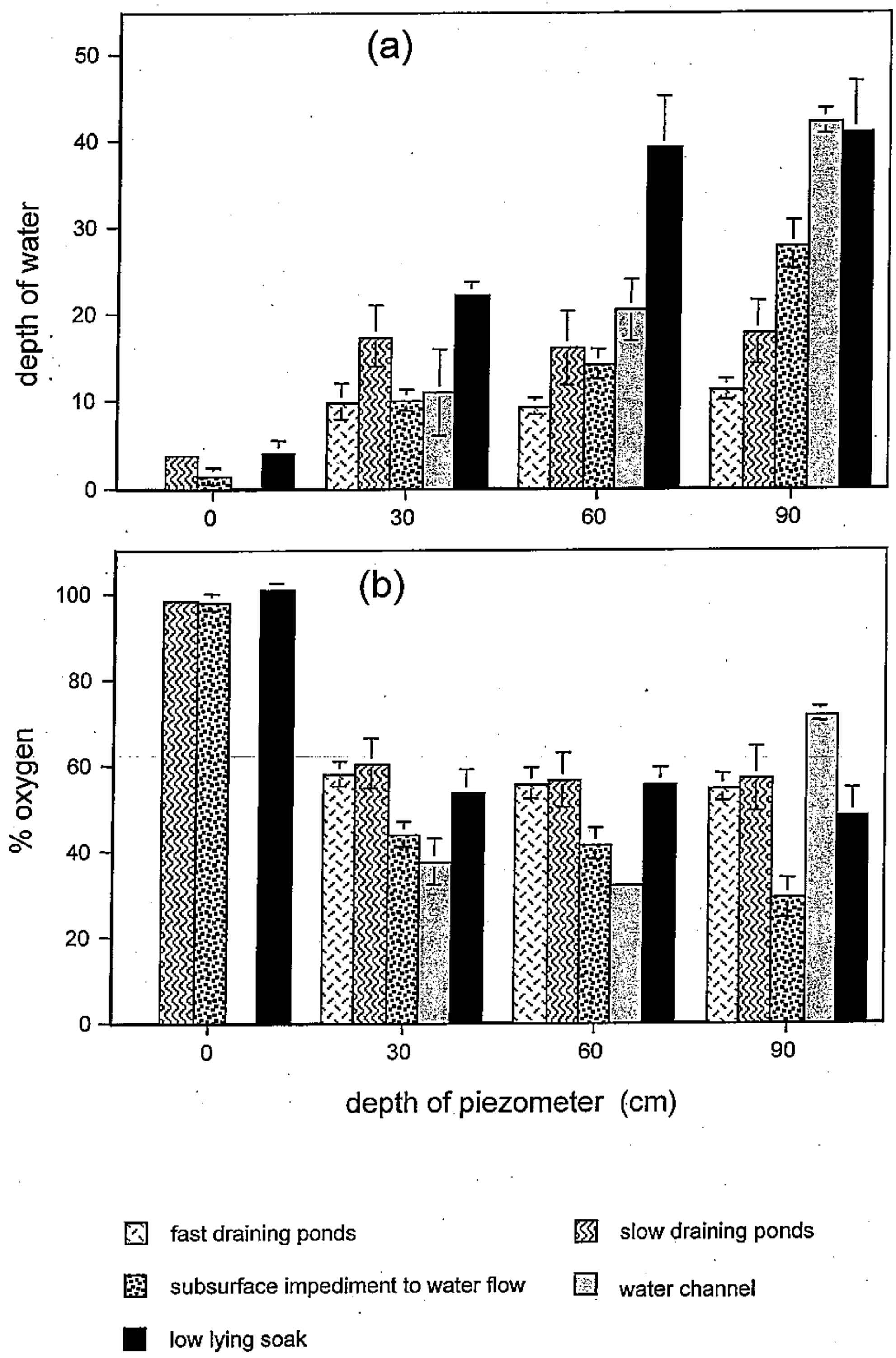

Figure 6. (a) water depth and (b) oxygen content (relative to the oxygen content of air) at the surface and in piezometers inserted 30, 60 and up to 90 cm below the surface for the different pond types. The values are the average for the different pond types across all 6 sites. All measurements were made within 2 days of rain. Bars = ± SE.

This study indicates that the potential exists in recently rehabilitated minepits for surface ponding to be associated with sub-surface ponding or waterlogging. The low oxygen content of sub-surface water would have detrimental effects on plant growth. The collar of *E. marginata* is very susceptible to infection by *P. cinnamomi* and surface ponding provides ideal conditions for infection development. Thus, the combination of surface ponds and sub-surface waterlogging would probably result in increased disease severity. This hypothesis is being examined in more detail in glasshouse experiments.

The presence of the hard clay layer at less than 90 cm depth in some of the study areas indicates that ripping has not significantly improved the vertical infiltration of these areas. Ripping techniques have been developed to relieve compaction and hence increase infiltration and root penetration. The areas should have been ripped to 1.2 m with the ripped area being directly below the bottom of the ripline. In these cases, ripping may not have been completed according to the standard or the clay layer may have reconsolidated after ripping. Further studies are required in rehabilitated minepits to examine the formation and drainage of ponds and the oxygen content of sub-surface water for several days after a rain episode. This will provide more detailed information on the likelihood that surface ponding is associated with severe (oxygen contents <20% of the oxygen content of air) waterlogging conditions. The need to maintain the standard of ripping is manifest.

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