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Wind erosion potential of reconstructed landforms

Tropicana Gold Project

AngloGold Ashanti Ltd
and
Independence Group NL

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Landloch Pty Ltd
Contact: Evan Howard
howardev@landloch.com.au

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Landloch Pty Ltd
A.C.N. 011 032 803
A.B.N. 29011032803

TOOWOOMBA OFFICE
PO Box 57
HARLAXTON QLD 4350
Phone (07) 4613 1825
Fax (07) 4613 1826

PERTH OFFICE
PO Box 1395
WEST PERTH WA 6872
Phone (08) 9480 0449
Fax (08) 9321 0320

Web site: www.landloch.com.au
Email: admin@landloch.com.au

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EXECUTIVE SUMMARY

The proposed Tropicana Gold Project (TGP) is located 330km east north-east of Kalgoorlie on the western edge of the Great Victoria Desert. The TGP is a joint venture between AngloGold Ashanti Australia Limited (70%; manager) and Independence Group (30%). The Great Victoria Desert landscape consists predominantly of Quaternary aeolian sand ridges interspersed with swale areas. The proposed site is generally vegetated with a mixture of tree, shrub, and grass species. Vegetation appears to be a significant factor in the stability of the dunes in terms of resistance to wind erosion.

Over the life of the project, proposed activities will disturb a proportion of the sand dunes in the local area; generating a quantity of sand suitable for use during restoration activities. Landforms constructed using the dune material will potentially have little surface cover for considerable periods during the life of the mine and after rehabilitation. Landloch was engaged to consider the risk associated with wind erosion of dune sand used during restoration activities. The susceptibility of the surface dune materials to wind erosion is largely determined by the materials' particle size distribution and soil structure. Sandy soils are typically non-cohesive and are readily loosened by the force of wind once the threshold wind velocity is exceeded. Materials located at depths greater than 0.6 m in the dunes show increased clay content, and are likely to behave differently when exposed to wind. Further assessment of the materials to be disturbed during the life of the mine, and in particular the dune materials deeper than 0.6 m is **highly recommended**.

The modal diameter of the surface dune material is 0.45 mm and is associated with a threshold wind velocity of 50.2 km/h (13.9 m/s) measured 10 m from the surface of the soil. Wind data (from Laverton) available for the area shows that wind gusts are, on average, 1.65 times greater than the average hourly wind speed, therefore an average hourly threshold wind velocity of 30 km/h was used to allow for wind gusts that exceed the average hourly wind speed. The threshold wind velocity of 30 km/h is exceeded 9 % of the time, and the majority of these "high wind" periods last less than 5 hours.

Without intervention, unvegetated soil or sand susceptible to wind erosion cannot be expected to revegetate. Surface stabilisation can be achieved by increasing surface resistance through placement of rock or vegetation debris on the soil or sand surface, or application of temporary surface treatments (adhesives). Temporary surface treatments are used in the minerals sands industry.

In terms of construction of the landform, there may well be benefit in initially constructing the eastern batter to its full design height and rehabilitating that slope prior to filling in the remainder of the landform (progressively moving to the west of the constructed slope). Ideally, the rock or vegetation debris should be applied to the entire windward slope. Rock need not be larger than approximately 5-10 mm in diameter to be effective in limiting wind erosion. Vegetation debris the size of small branches or larger is also likely to be effective. Levels of cover reported as effective for minimising wind erosion range from 20-40 % for rock, and 30-50 % for vegetation debris. Application of temporary surface treatments typically offer protection for 3-6 months, after which reapplication is necessary.

1. INTRODUCTION

1.1 Background

The proposed Tropicana Gold Project (TGP) is located 330km east north-east of Kalgoorlie on the western edge of the Great Victoria Desert (Figure 1). The TGP is a joint venture between AngloGold Ashanti Australia Limited (70%; manager) and Independence Group (30%) (Figure 1). The Great Victoria Desert landscape consists predominantly of Quaternary aeolian sand ridges interspersed with swale areas. The site is generally vegetated with a mixture of tree, shrub, and grass species (Figure 2). The sand dune areas are dominated by vegetation that provides surface contact cover (Figure 3).

Over the life of the project, proposed mining activities will disturb a proportion of the sand dunes in the local area; generating a quantity of sand suitable for use during restoration activities. Landforms constructed using the dune material will potentially have little surface cover for considerable periods during the life of the mine and after rehabilitation. Landloch was engaged to consider the risk associated with wind erosion of dune sand used during restoration activities.

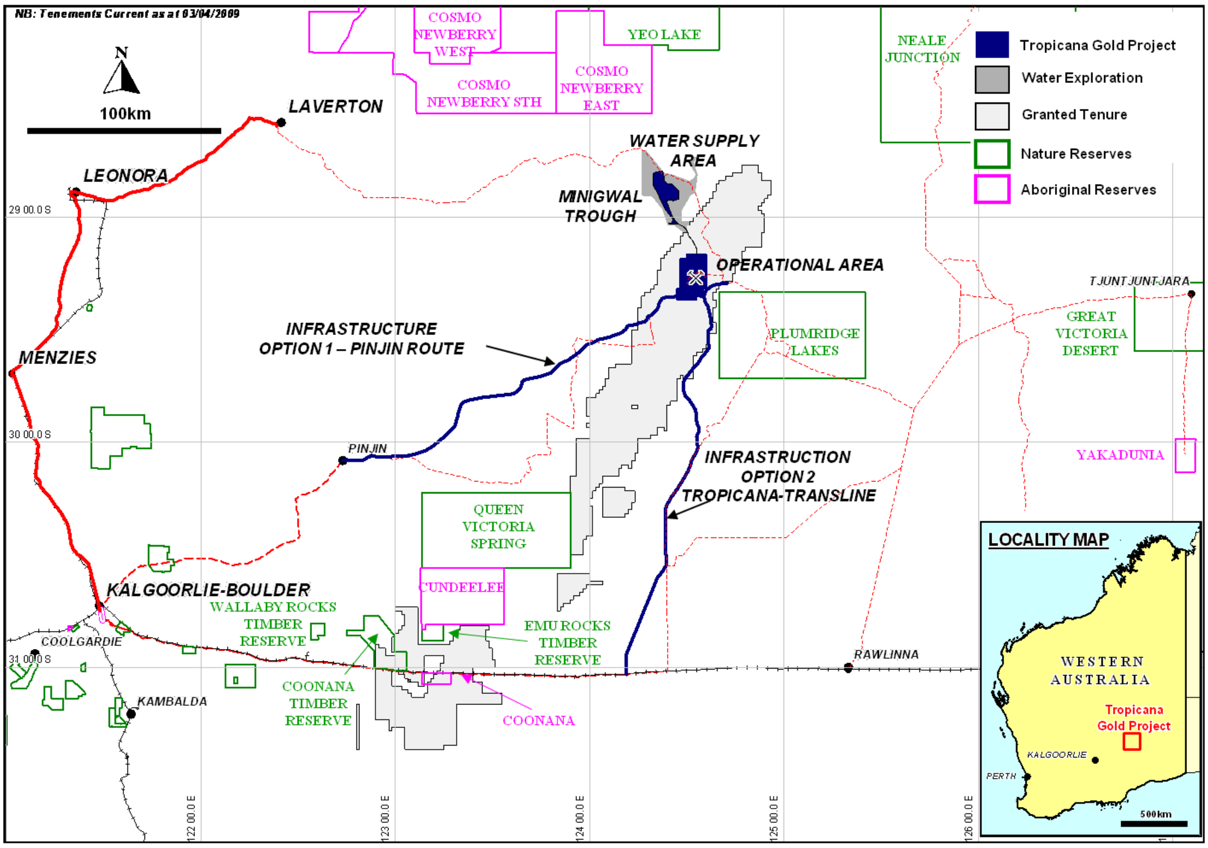

***Figure 1**: Location of the Tropicana Gold Project*

Figure 2: *Vegetation in swales (foreground) dominated by trees and shrub species. Dune materials (background) showing low growing vegetation.*

Figure 3: *Vegetation on the dunes provides protection against wind erosion.*

1.2 Site climate

The climate at TGP is arid, with an average annual rainfall of approximately 200 mm (based on data from Laverton). The majority of rainfall occurs during summer and autumn (Figure 4). The largest daily rainfall event recorded between 1960 and 2008 was 51 mm. Of all the rainfall events recorded between 1960 and 2008, 99 % were less than 10 mm. A daily rain event of 41 mm has an average recurrence interval of approximately 10 years. Given the scarcity of significant rainfall events, the soils at the TGP are normally dry and do not benefit in any lasting or reliable way from the stabilising effect of increased soil moisture. (Wet soil is considerably less susceptible to wind erosion than is dry soil).

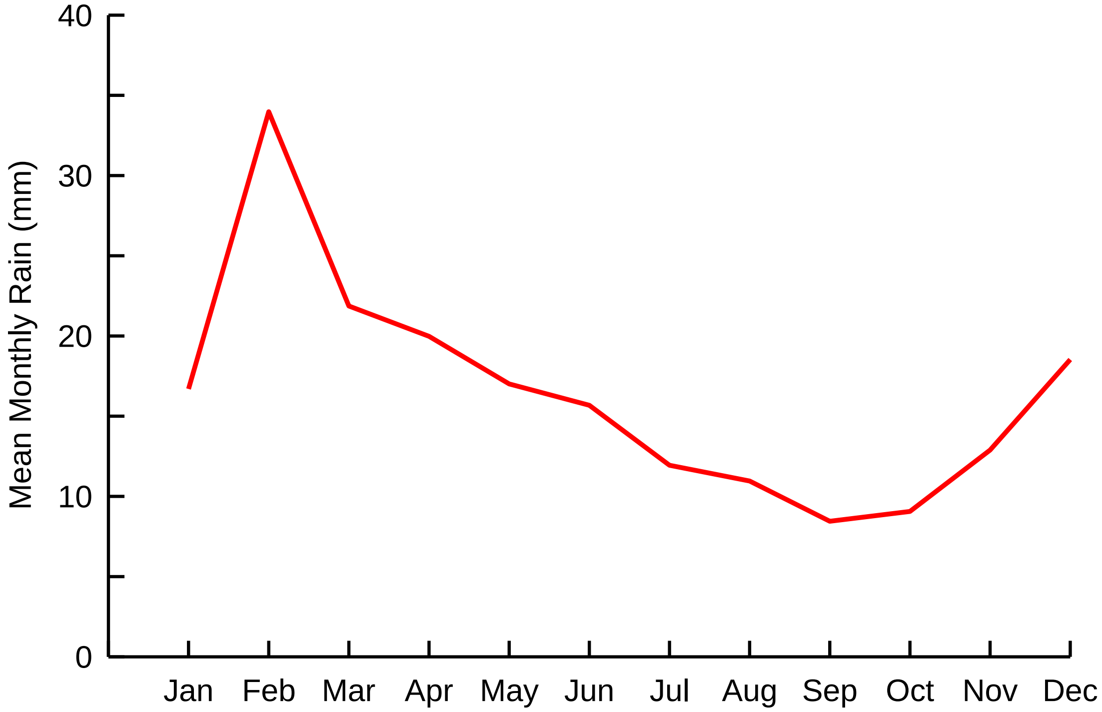

Figure 4: *Mean monthly rainfall for Laverton from 1960 to 2008.*

1.3 Basic principles of wind erosion

Erosion occurring due to wind is a function of the force applied to the soil surface by the wind and the resistance of the soil surface to those forces. Wind forces are a function of wind speed, and duration of the wind will further determine the total amount of soil transported by a wind event. Surface resistance is a function of soil type, texture and moisture, and vegetation cover and architecture. Essentially, when the resistance of the soil surface — as expressed by a threshold wind velocity — is greater than the prevailing wind conditions, soil particles are not mobilised and transported and wind erosion does not occur. As the wind velocity increases and exceeds the threshold wind velocity, soil particles begin to move and wind erosion occurs. Wind erosion is highly episodic, with long periods of little activity followed by significant soil loss in an event that might only last a relatively short period of time.

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Although wind erosion generally increases with increasing wind speed and increasing wind duration, this trend can be confounded by changes in soil properties with depth if more resistant soils become uncovered as eroded materials are transported. Further, surface conditions can change during windy periods. Lighter, less dense particles are typically removed first and leave heavier, denser particles on the surface, effectively increasing the surface's resistance to wind erosion. This hardened surface condition persists until wind speeds exceed the increased threshold wind velocity.

There are three modes of transport of particles by wind (Figure 5). They are:

1. **Suspension** — winds mobilise, hold, and transport fine particles over very long distances. The particles are small enough for their fall due to gravity to be slow and counteracted by air turbulence. Silty and loamy particles are easily transported via suspension, whereas sand particles are not. Transport of clay particles via suspension depends on their degree of aggregation, with well aggregated clays being less easily transported than unaggregated clays.

2. **Saltation** — progression of particles by successive jumps. Particles sizes most susceptible to saltation are in the size range 0.075 to 0.6 mm. The modal grain size of most aeolian and dunal sands is 0.2−0.4 mm (FAO, 1985); therefore saltation is the dominant mode of transport for the majority of materials found in dune areas.

3. **Creep** — movement of particles along the soil surface. Creep occurs when wind forces are insufficient to lift particles into the air. Small pebbles and even boulders can be moved by creep if wind forces are sufficient. Creep is often initiated by collision of saltating particles and the larger particles.

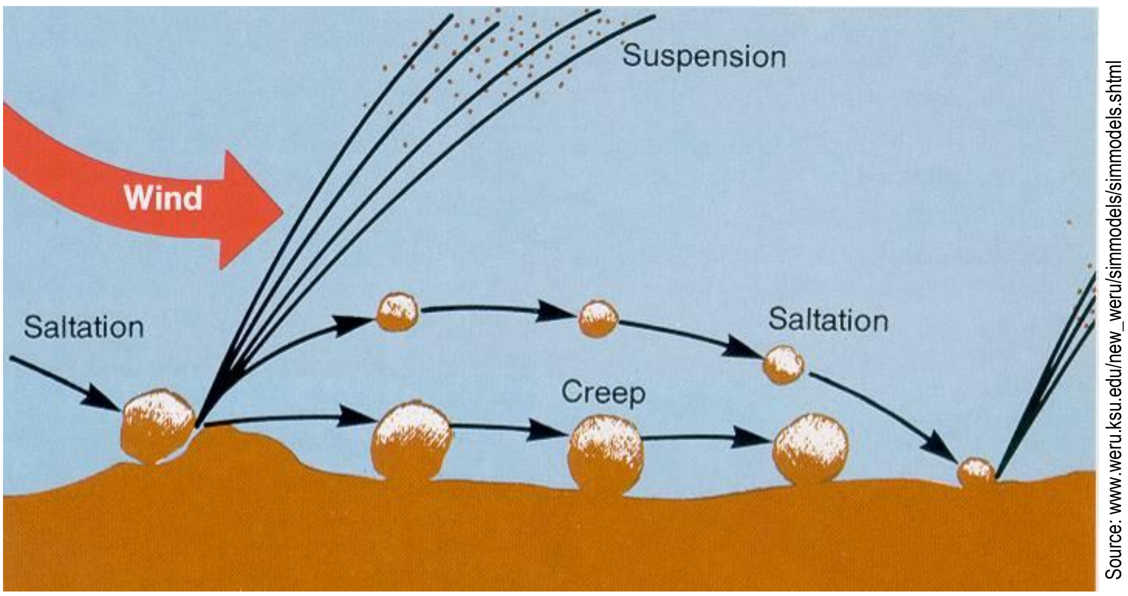


Figure 5: *Modes of transport of particles by wind.*

2. METHODS

2.1 Overview

Although it would have been preferable to directly model rates of potential wind erosion from constructed landforms, that was not practicable.

Modelling wind erosion over large areas requires large atmospheric, landscape, and vegetation data sets. The availability of these data sets at suitable scales in Australia is limited, and data are typically non-existent in arid areas where wind erosion is likely to be more of a concern. Current modelling of wind erosion at regional and continental scales in Australia generally produces mapping suitable for areas greater than 50,000 km^2, four times the size of the TGP. The usefulness of this modelling approach for the development of site specific management strategies is obviously limited. Large scale wind erosion modelling also requires significant computing power not available in typical desktop computers. As an example, wind erosion modelling for Australia using broad scale aerodynamic, soils, and vegetation data sets uses designated high performance computing installations, takes approximately 30 hours to run the model, requires about 120 Gb/y of storage space (a ten year model run would therefore need about 1,200 Gb), and takes 10-15 days to validate the model results (Butler *et.al*, 2007).

Assessment of wind erosion at smaller scales often only considers relatively simple landscapes i.e. linear slopes such as farm paddocks, and simple wind conditions. Variability in landscape, atmospheric and vegetation conditions is often not accounted for and results of these assessments are typically valid for relatively specific site conditions. They do, however, enable a broad understanding of potential for wind erosion and allow development of general strategies for minimisation of wind erosion potential.

The approach adopted to assess the likelihood of wind erosion at the TGP and to provide guidance on strategies to manage and mitigate the impacts of wind erosion was similar to the methods used for erosion assessment at small scales, and involved:

1. Assessment of important characteristics of Quaternary aeolian sands at the site.
2. Determination of the threshold wind velocity required to initiate wind erosion of those sands.
3. Use of wind data for the area to assess the likelihood of wind erosion occurring from an unvegetated surface.

2.2 Material properties and site wind data sources

A sample of the dune material to be disturbed was analysed for particle size distribution using an automated settling column (Loch 2001) to give greater detail on size distribution. These data were compared with published data for similar aeolian sands. Unpublished data for similar materials measured by Landloch were also used.

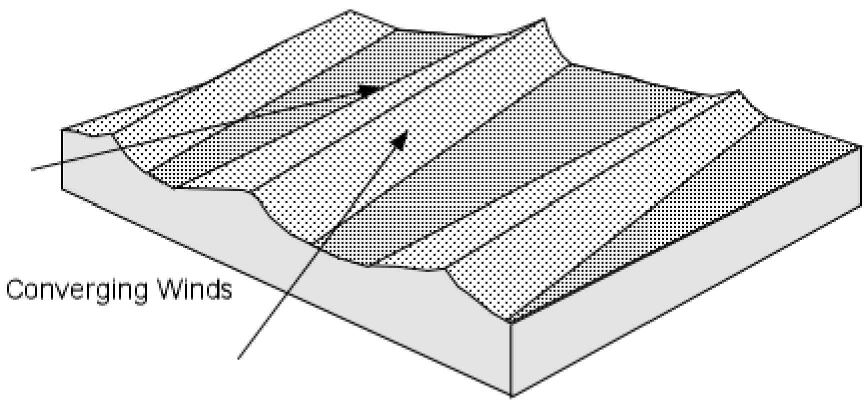
Wind data for speed, direction, and wind gust were sourced from the Australian Bureau of Meteorology weather station at Laverton. Wind data exist for Laverton from 1993 to 2008. Data between 1993 and 1998 have a half-hourly time step, and data between 1999 and 2008 have an hourly time step.

Aerial imagery and observations from Landloch's site visit in March 2008 were used to determine the orientation of the sand dunes relative to the current prevailing winds. Information on resources available for use in strategies to minimise the risk of wind erosion was also used.

3. DATA AVAILABLE AND COLLECTED

3.1 Observations of dune structure and activity

During Landloch's site visit, no evidence of active wind erosion was observed. Existing surface vegetation appeared to be sufficient to greatly increase surface resistance to wind erosion. Dunes on the TGP are linear in shape and likely to have been formed in circumstances where there are two converging dominant wind directions (Figure 6). Where only one direction is dominant, singular, large dunes are typically formed, and where there is no dominant wind, complex pyramidal shaped dunes are formed. Where sand is sourced over a large area, long dunes similar in appearance to linear dunes can be formed.



Source: www.tulane.edu/~sanelson/geol111/deserts.htm

Figure 6: *Formation of linear dunes from two converging wind directions.*

Bagnold (1941) reports that linear dunes do not necessarily move laterally for any great distance, and can grow in size while remaining immobile. This occurs when the dune is essentially symmetrical in cross section, with winds from one direction moving sand to the dune, and winds from the other direction effectively moving the sand along the dune, causing it to elongate. The growth of such dunes is ultimately limited by sand supply. The vegetation on these dunes may have developed as a result of a lack of supply of "new" sand, or due to a change in wind direction after the dunes were established (not likely since the current prevailing winds can explain the orientation of the dunes). Linear dunes can be many kilometres long and may be discontinuous.

3.2 Properties of dune sand

Landloch previously sampled materials from the TGP for particle size distribution (Landloch, 2008). Table 1 lists the results for the dune and swale materials sampled at that time.

Table 1: *Particle size distributions of samples taken on the Tropicana Gold Project.*

Description	Location	Depth (mm)	Clay (%)	Silt (%)	Fine Sand (%)	Coarse Sand (%)
TPRC 190D	Dune	0–300	9	2	27	63
		600–900	19	1	29	52
TPRC 788	Swale	0–1000	4	3	32	64
TPRC 018	Swale	0–1000	9	2	34	57
TPRC 182	Swale	0–300	6	1	29	64
		900–1000	9	3	39	51

The particle size distribution of the dune material (TPRC 190D) was further analysed to determine its modal size. Figure 7 gives the particle size distribution for the dune material.

The particle size of the dune material is distributed around a modal size of 0.45 mm. This compares well with data measured previously by Landloch for dune material from the southern WA Goldfields (0.3–0.5 mm) and is slightly higher than Quaternary aeolian sands sampled from Toolara, QLD, which had a median size of 0.2–0.3 mm. FAO (1985) reports that grain sizes ranging from 0.15–0.5 mm are usually involved in saltation and are commonly found in wind-blown deposits. Dune materials from the TGP contain particles with grain sizes susceptible to wind erosion.

Quaternary aeolian sands at the TGP are dominated by quartz with a grain density of approximately 2.65 g/cm^3.

Dune material sampled showed increasing clay content with increasing sampling depth. Swale materials sampled appear to have higher sand contents than the dune materials throughout the surface 1.0 m sampled. No particle size or soil chemistry data exist for dune or swale materials deeper than 1.0 m. This information will be important to determine the erodibility of this material due to both wind and water. As clay content increases, issues of clay aggregation or dispersion — depending largely on soil salinity and sodicity — will become increasingly important.

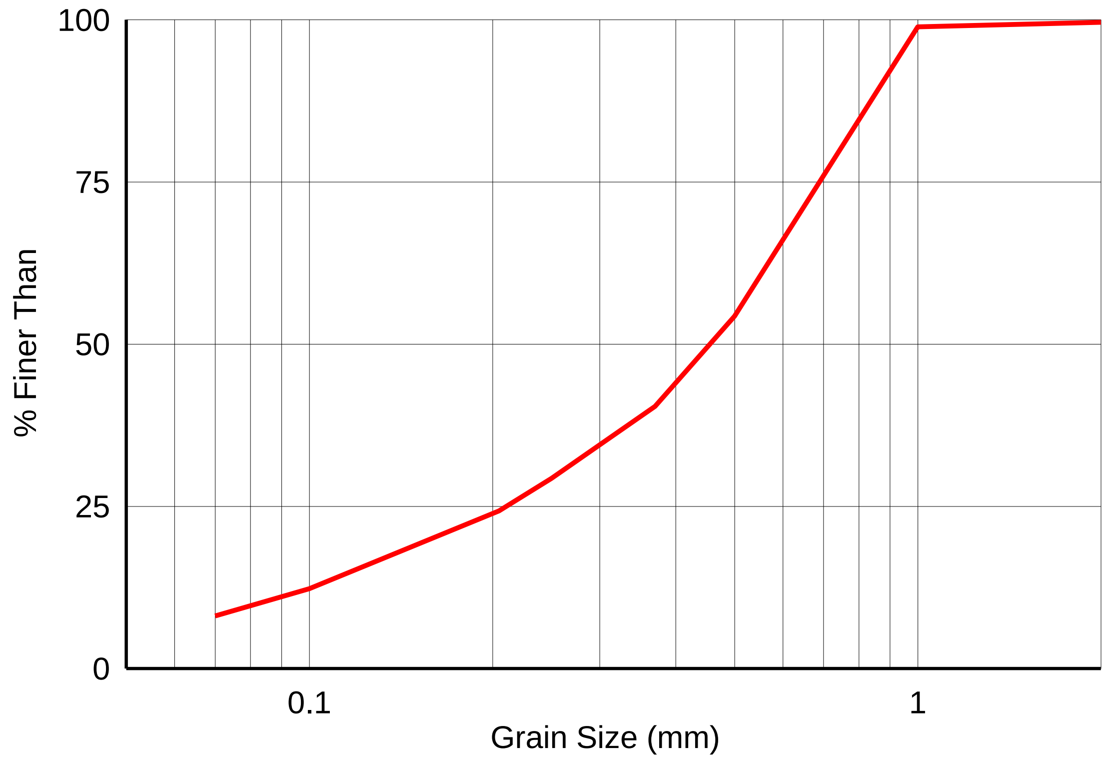


Figure 7: *Particle size distribution of dune material (TPRC 190D) sampled from the surface 0.3 m.*

Dune materials sampled for mineral sands operations in Western Australia also show increased clay content as sampling depth increases. Similarly, sampling of dune materials in the southern WA Goldfields has shown increased clay contents with depth. Construction of landforms using these higher-clay materials from depth has been generally unsuccessful, due to soils dispersing, setting hard (to depths greater than 500 mm), and being incapable of supporting vegetation. Subsequent ripping and seeding operations have not reduced the tendency for the soil to disperse and set hard.

If present, clay materials in the dunes at the TGP are likely to be saline and sodic. Further investigations of clay content at depth within the dunes will be important if the dunes are to be completely disturbed as a result of mining. Characterisation of these materials will be important to determine their:

- soil chemical properties;
- tendency to disperse and set hard;
- ability to support vegetation; and
- depths of stripping to source useful “topsoil” material for rehabilitation works.

3.3 Threshold wind velocity for initiation of wind erosion

Table 2 provides threshold wind velocities for a range of sands with different modal sizes. Threshold wind velocities relate to wind velocity at 10 m above the soil surface as this is the nominal height at which the Australian Bureau of Meteorology measures wind parameters.

Table 2: *Threshold wind velocities for different grain modal sizes.*

Grain Modal Size (mm)	Threshold Wind Velocity @ 10 m (m/s)	Threshold Wind Velocity @ 10 m (km/h)
0.15	8.7	31.3
0.20	9.9	35.5
0.25	10.8	39.0
0.30	11.7	42.2
0.35	12.5	45.1
0.40	13.3	47.7
0.45	13.9	50.2
0.50	14.6	52.5

These threshold velocities are similar to those used by Robertson (1987) in a WA Department of Agriculture assessment of wind erosion risk for agricultural areas of Western Australia.[1]

For the TGP, the modal sand size of 0.45 mm is associated with a threshold wind velocity of 50.2 km/h (13.9 m/s). Table 3 shows average hourly wind speed ranging from 30−60 km/h and the associated typical measured wind gusts. Over this range of average hourly wind speed, wind gusts are, on average, 1.65 times greater than the measured average hourly wind speed. Therefore, for the analysis of wind data for the TGP, an average hourly threshold wind velocity of 30 km/h (50.2 km/h ÷ 1.65) was used to allow for wind gusts that exceed the average hourly wind speed.

Table 3: *Average hourly wind speeds the associated typical spread of measured wind gusts.*

Average Hourly Wind Speed (km/h)	Wind Gusts (km/h)		Wind Gust as an Averaged Multiple of Wind Speed
	Min	Max	
30	32	79	1.84
40	44	90	1.68
50	56	102	1.58
60	68	113	1.51

[1] Robertson (1987) reports a threshold wind velocity of 29 km/h measured at a height of 2 m. This is equivalent to a wind speed of 32 km/h when measured at a height of 10 m. Typical grain sizes would range from 0.2−0.3mm.

Assessment of erosion risk assumes an unvegetated soil surface, as this corresponds to the time at which erosion risk is greatest. Establishment of vegetation will greatly reduce wind erosion potential.

4. WIND DATA

4.1 Analysis methodology

Wind speed and direction data for Laverton from 1993−2008 were sourced and assessed to determine the:

1. Frequency of different wind speeds.
2. Prevailing wind direction of winds that exceed the threshold wind velocity.
3. Typical duration of wind events that exceed the threshold wind velocity.
4. Coincidence of high wind and rainfall events.

Wind speed data were collected on an hourly basis (except for 1993−1998 when data were collected half-hourly). Wind speed data are an average wind speed over the sampling period, and wind gusts can occur that have speeds greater than the average wind speed. Wind gust data show that measured wind gusts can be 1.5−3 times greater than the average wind speed, though on average they are 1.65 times greater. The maximum average wind speed measured was 81 km/h. The maximum wind gust measured was 181 km/h.

4.2 Frequency of different wind speeds

The frequency of different wind speeds is shown in Figure 8. Winds greater than 30 km/h comprise a small proportion of the wind data recorded.

Approximately 9 % of the recorded average wind speeds exceeded 30 km/h. The vast majority of events do not have the potential to cause wind erosion, however, significant sand movement from unvegetated soil surfaces can occur in relatively short periods of time. Some periods with average wind speeds less than 30 km/h had wind gusts greater than 30 km/h, and these periods also have potential to cause wind erosion.

4.3 Prevailing direction of winds exceeding the threshold wind velocity

Figure 9 shows prevailing wind directions for winds that exceed 30 km/h. Winds greater than 30 km/h predominantly come from the east to south east (approximately 47 %). A smaller proportion (27 %) of winds greater than 30 km/h come from the west, and winds exceeding the threshold wind velocity only occasionally come from the north or south.

This distribution of strong winds is consistent with the formation of linear dunes that require two converging winds; in this case from the east and south-east. The resultant dune would be orientated in an east-west direction.

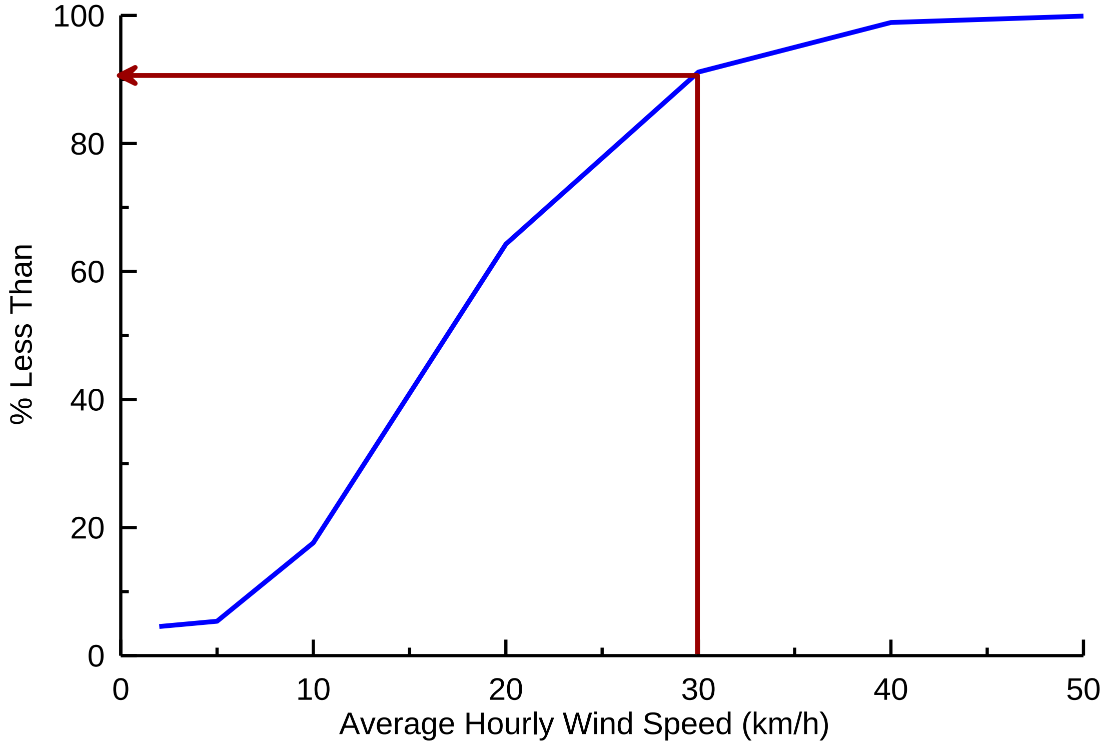


Figure 8: *Frequency of different wind speeds at Laverton.*

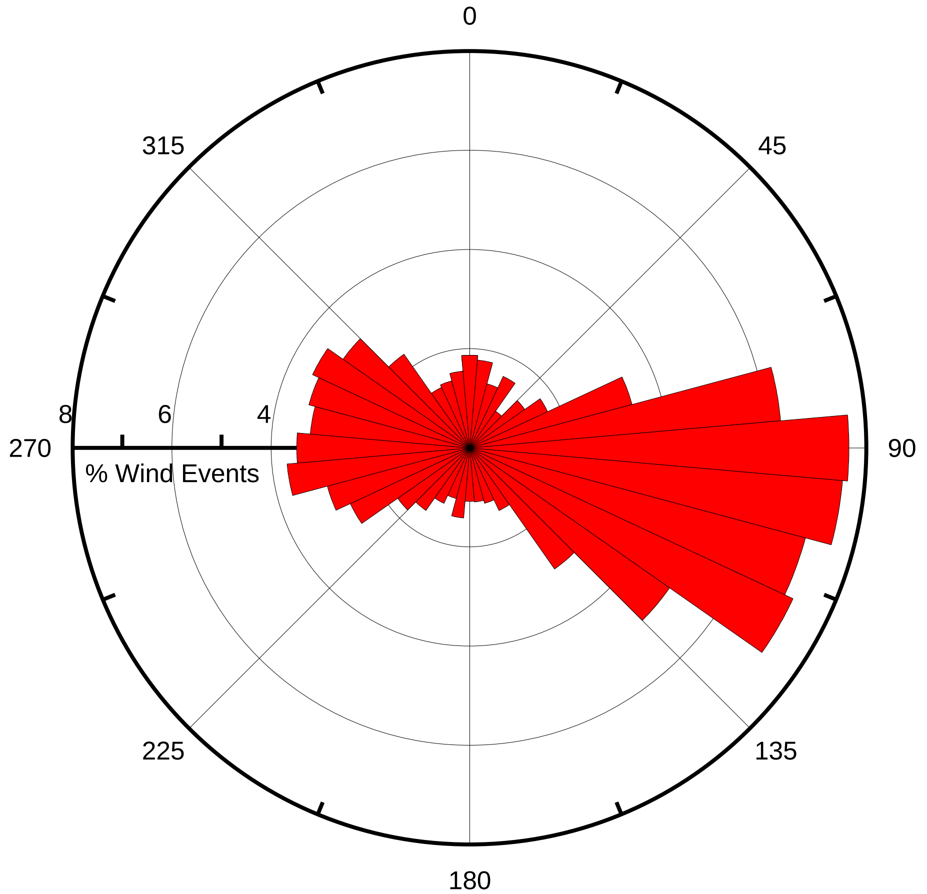


Figure 9: *Percentage of wind exceeding 30 km/h from various directions (0º is equivalanet to north).*

4.4 Duration of wind events where the threshold velocity is exceeded.

Almost half of the wind events with velocities greater than 30 km/h last no longer than an hour (though another wind event can follow shortly after that event) and 94 % of all winds last no longer than 8 hours (Figure 10). The maximum duration of a single wind event where the threshold velocity to cause erosion was exceeded was 46 hours. However, wind events longer than 16−20 hours are generally uncommon.

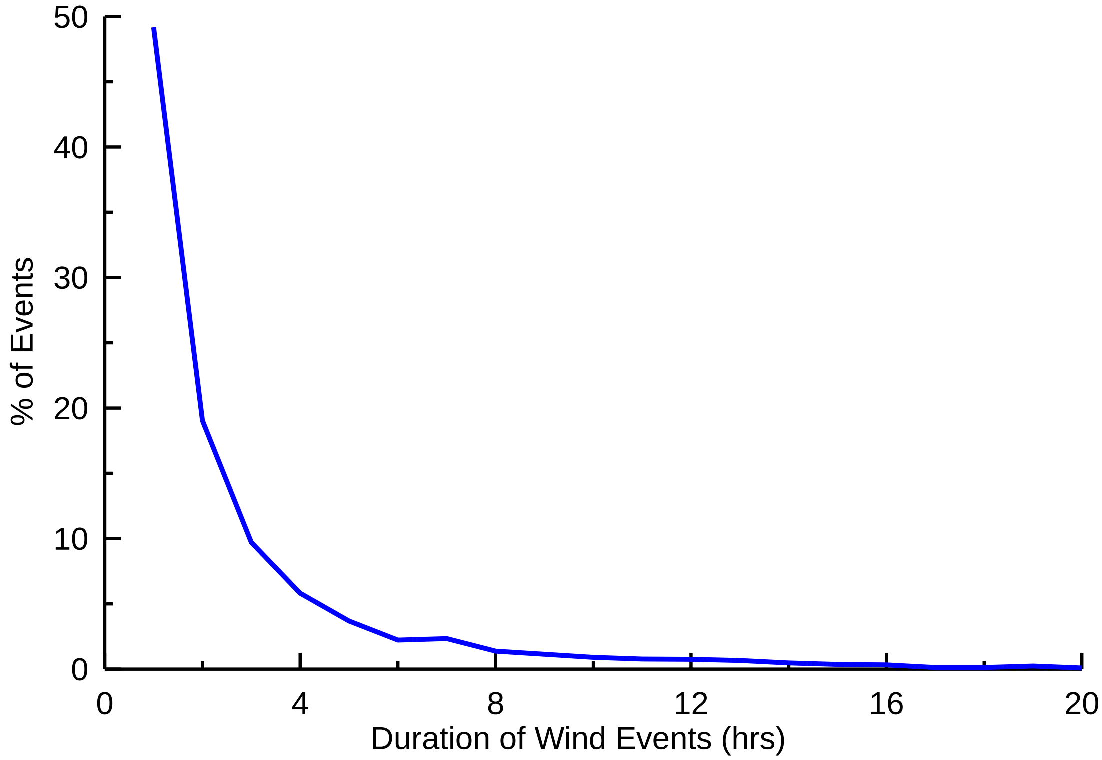


Figure 10: *Duration of wind events when the threshold wind velocity is exceeded.*

The rate of sand movement can be estimated using the following equation (FAO, 1985)[2]:

$$Q = \frac{10^{-4}}{(\log 100z)^3} \times t(v-30)^3$$

where Q = mass of sand moved over 1m wide front (tonnes)
t = wind duration (hours)
v = wind velocity (km/h)
z = height of wind measurement (m)

The rate of sand movement is typically directly proportional to the duration of the wind i.e. a wind of a certain velocity lasting 2 hours will transport twice as much sand as the same velocity wind lasting only one hour. However, the rate of sand movement can change as the duration increases, as the small sized grains are

[2] Equation adjusted to reflect a threshold wind velocity of 30 km/h

transported leaving larger (or denser) grains with greater erosion resistance on the surface. This surface condition prevails until a wind with sufficient velocity to transport the more resistant grains occurs, at which point more erodible grains are made available for transportation.

As the wind velocity increases, the rate of change of sand movement also increases (cube relationship). Hence, a wind that exceeds the threshold velocity by 10 km/h transports 8 times more sand than a wind that exceeds the threshold velocity by 5 km/h. Figure 11 shows the relationship between sand movement, wind velocity and duration.

Figure 11 shows estimated sand movement over a 1 m wide front for various wind speeds. As the duration of wind events increases, the quantities of sand that are able to be moved also increase. As well, sand movement is proportional to the cube of the wind speed. Hence, as wind speed increases past the threshold wind velocity, the rate of sand movement increases exponentially. The TGP will experience winds exceeding the threshold wind velocity approximately 9 % of the time. Of these events, approximately 30−50 % will last longer than 2−3 hours.

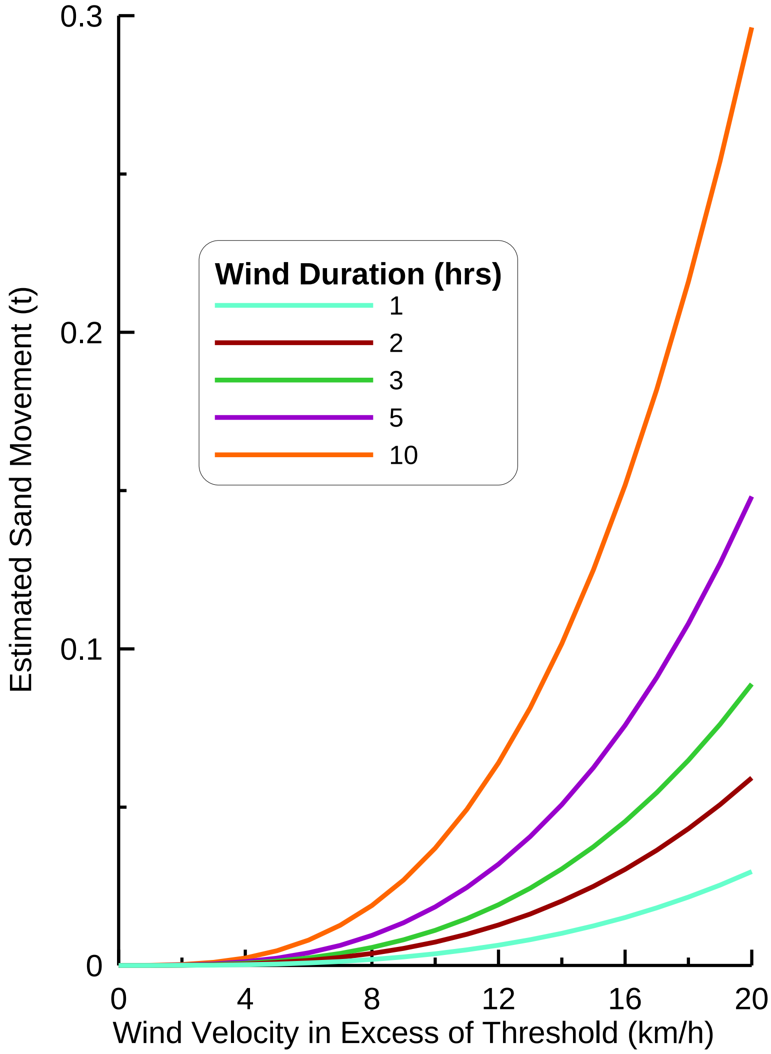


Figure 11: *Estimated sand movement over a 1 m wide front for various wind durations.*

Actual rates of sand movement vary with time and will tend to decrease as the more erodible particles are selectively removed by the wind, leaving less erodible particles on the surface. This less erodible surface layer persists until faster winds occur that are able to erode the heavier particles. In turn, this erosion once again exposes the smaller, more erodible particles, and the process of erosion can continue at lower wind speeds. Data shown in Figure 11 assume no changes to the erodibility of the surface with time, and hence will overestimate actual rates of sand movement. Nevertheless, it does illustrate the impacts of wind duration and wind speed on erodible surfaces.

5. MANAGEMENT OF WIND EROSION

5.1 Positioning dump relative to prevailing winds

Wind erosion in the TGP area is currently limited by the erosion resistance provided by vegetation. The existing dunes are orientated in an east-west direction, in a similar direction to the prevailing winds. This orientation limits the movement of sand to within the dune area itself, and is not likely to cause lateral migration of the crest of the dunes.

If the dunes are disturbed and placed in a landform orientated perpendicular (running north-south) to the current prevailing wind, the risk of wind erosion (to effectively cause dune migration) increases, and successful revegetation of the highly erodible crest of the dune will be particularly difficult. Orienting the landform in an east-west direction would be desirable if practicable.

If – as appears likely - this orientation is not possible, armouring of the windward side (and particularly the crest) will be required. This will be necessary until vegetation is established and able to provide surface erosion resistance. Without intervention, unvegetated sand susceptible to wind erosion cannot be expected to revegetate due to:

- injury of seedlings due to abrasive action of blowing sand;
- exposure of newly developed root systems as sand moves; and
- young seedlings being buried by sand.

Increased surface resistance can be achieved by:

- placement of vegetative debris on the surface;
- placement of gravel and/or rock on the surface; and/or
- application of temporary surface treatments (adhesives).

Ideally, the rock or vegetation debris should be applied to the entire slope.

Chepil *et al.* (1963) found that rock need not be larger than approximately 5-10 mm in diameter to be effective in limiting wind erosion. Approximately 20-40 % of the soil surface should be covered. This is similar (though slightly lower) to the surface cover required from vegetation (Carter, 2002).

Vegetation debris the size of small branches or larger is likely to be effective. Approximately 30-50 % of the surface should be covered (Carter, 202).

If supply of rock or vegetation debris is limited and these rates of surface coverage cannot be achieved, preference should be give to placement of this material on the:

- crest of the dune where turbulent wind flows tend to increase erosion; and
- windward side where the largest wind force is experienced.

Also, where supplies of rock or vegetation are limited, a checkerboard pattern could be employed, with lines of these materials intersecting to form areas of 5−6 m². Wind erosion can reach its maximum rates in less than 5 m, and lines of rock and vegetation should be placed as close together as possible. The height of each line need not be greater than 0.1−0.2 m.

Application of rock and/or vegetative debris also has added benefit in that it will provide some water erosion resistance.

Application of temporary surface treatments is popular in the mineral sands industry. Products such as Rainstorm's Gluon have been used widely and successfully, but only offer protection for 3-6 months, after which reapplication is necessary. The actual period of protection is dependent on the thickness of the layer applied, and hence will depend on the application rates and the uniformity of application. The supplier of Gluon states that it does not inhibit plant growth and application rates of 500 L/ha have been used successfully in mineral sands operations. The typical cost of applying the product is approximately $2,000/ha and for this reason, this strategy is likely to be more expensive than using rock or vegetation. It does however, provide greater flexibility and can be applied rapidly after disturbance if vegetation or rock are not available.

Also used is incorporation of clays into the surface layers to improve aggregation, increase the effective particle size and increase erosion resistance. Incorporation of 2−4 t/ha of clay — to a depth of 25 mm — has been shown to greatly reduce wind erosion on sandy loam soils (Hsieh and Wildung, 1969). This option will not be suitable, however, if the available clays are dispersive and potentially hard-setting.

Increasing form roughness (rip lines constructed from the dune materials) of the dune material without application of any other surface treatment is unlikely to reduce erosion potential (Armbrust *et al.*, 1964).

5.2 Vegetation and dune stabilisation

Establishment of vegetation is likely to be highly desirable and is likely to provide the long-term soil stability required. Chepil and Woodruff (1963) state that vegetation can reduce wind forces at the soil surface by as much as 99 %, though the actual effectiveness is dependent on the amount, type and orientation (standing or flat) of the vegetation. Figure 12 shows the impact of standing vegetation on sand movement (Robertson, 1987).

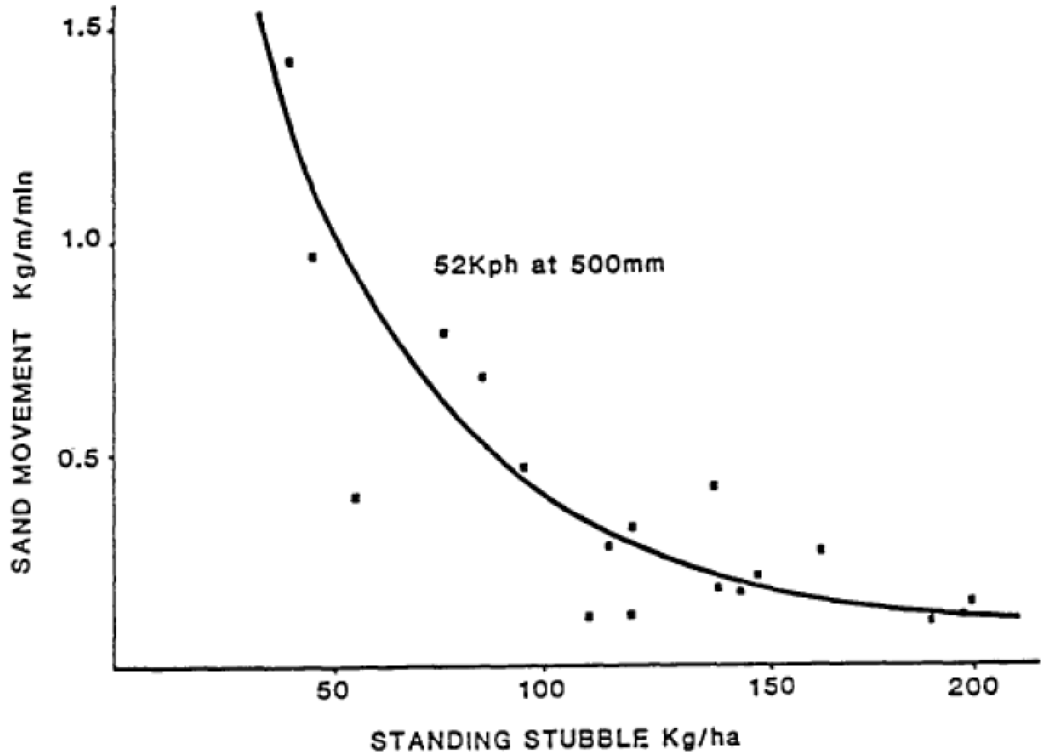


Figure 12: *Impact of vegetation on sand movement.*

For adequate protection against wind erosion, approximately 30−50 % of standing vegetation cover is required (Carter, 2002). Height of vegetation should be greater than 0.1 m to offer significant improvements to erosion resistance (Leys, 2003). This level (or better) of vegetation is achievable at the TGP, and currently exists on the undisturbed dunes.

Establishment of vegetation is likely, however to require stabilisation of the soil surface using rock, tree debris, and/or temporary surface treatments. Failure to provide a stable soil surface in which vegetation can establish is likely to cause:

- seedling injury;
- exposure of newly developed root systems; and
- young seedlings to be buried.

Importantly, current vegetation on the dunes is likely to be highly dependent on the increasing clay content with depth. These deeper layers will hold water that is extremely likely to be used by the vegetation, and successful rehabilitation of the dune materials must consider the water holding capacity of the soil profiles constructed. Failure to do so is likely to limit vegetation vigour and growth, and increase the susceptibility of the soils to erosion. Alternately, application of rock to the soil surface will provide erosion resistance, decreasing the importance of vegetation for stability.

5.3 Timing of rehabilitation works

Wind events that exceed the threshold velocity are rarest from April to August, and most common from November to January (Figure 13). Rainfall likely to be useful for rehabilitation activities largely falls from December to March (Figure 4).

The schedule of rehabilitation activities would therefore be:

1. placement of dune materials carried out completed during April to August and completed in August.
2. surface treatments (rock, vegetation debris, temporary surface treatments etc) applied in August/September
3. seeding of the bare surfaces from October to November and completed in November.

This process can be applied, particularly to the windward side of the waste landform in stages as the height of the landform increases. If lines of rock or vegetation debris are used rather than spreading them evenly over the surface, this operation should be performed after seeding. This would result in seeding needing to be performed in August/September, with placement of the surface treatments in October/November.

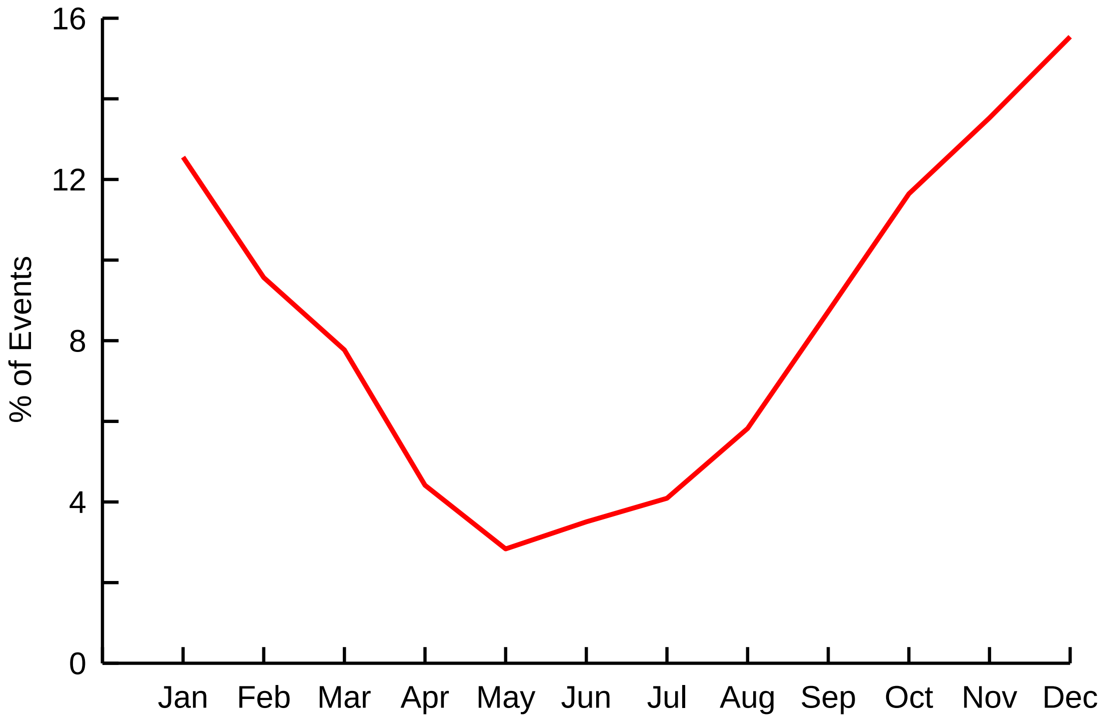


Figure 13: *Timing of wind events that exceed the threshold wind velocity.*

5.4 Options for landform design, construction, and rehabilitation

Because the orebody has a north-south orientation, it is anticipated that economics of hauling waste will dictate that the associated waste dump will have a similar north-south orientation. That will result in an east-facing batter slope that will have maximum wind erosion potential, but also means that works to control wind erosion can be concentrated on that (windward) batter slope.

In terms of construction of the landform, there may well be benefit in initially constructing the eastern batter to its full design height and rehabilitating that slope prior to filling in the remainder of the landform (progressively moving to the west of the constructed slope). If supply of vegetation debris is limited and 30-50 % cover cannot be achieved over the entire landform, sufficient material could be stripped from the total landform footprint and placed on the windward face to provide rapid surface stabilisation. There may even be scope to leave some vegetation from the total landform footprint uncleared and able to be used on the top of the dump as the landform increases in footprint.

Construction in this manner would result in the establishment of a vegetated surface on the windward side as quickly as possible, which may also reduce issues for the site with respect to dust (which could impact on both human health and machinery function). Necessary remediation works can also be performed during the life of the mine, minimising the risk of costly rehabilitation activities near the end of the mine life when much of the machinery required may not be on site any longer.

Subsequent construction of the landform over the life of the mine would essentially continually increase the area of the top of the landform. This newly created area can be rehabilitated on an annual basis, leaving only the leeward side to rehabilitate near the time of mine closure. The leeward side has the lowest risk of wind erosion, and is likely to require the least intervention to create a stable surface on which vegetation can establish.

Although uncertainties with respect to the exact volumes of waste likely to be excavated could create some difficulties, the above approach would have advantages of:

- drastically reducing the period of time over which batter slopes would be vulnerable to wind erosion and require stabilisation;
- enabling a range of techniques (vegetation debris, temporary surface treatments) to be applied in a timely manner to achieve best possible results;
- minimising the lengths of time for which vegetation debris would need to be stockpiled, thereby minimising any risk of the stockpiles being ignited by bushfires; and
- enabling almost direct transfer of “topsoil” material from stripping to rehabilitation, thereby maximising benefits from existing soil seed banks.

6. RECOMMENDATIONS

Wind erosion is largely dependent on particle size. The surface materials from the dunes at the TGP have a modal size that is likely to be highly erodible by wind.

Landform construction using the dune surface materials should focus on minimising the exposure of unvegetated surface to high velocity winds. The rehabilitation schedule outlined in section 5.3 has the potential to reduce the risk of wind erosion. When this schedule is coupled with initial construction and rehabilitation of the windward batter and subsequent rehabilitation of the expanding landform top, the risk of wind erosion is further reduced.

Construction of the landform using conventional lifts is likely to result in larger areas (windward batter and landform top) being exposed to wind. If conventional lifts are used, stabilisation of the top of the landform will be important and will require use of rock, tree debris, and/or temporary surface treatments.

Dune materials found deeper than approximately 0.6 m show increased clay content, and these materials are likely to behave differently when exposed to wind. These materials also have the potentially to be saline and sodic, and if placed near the surface are likely to become increasingly unstable. Further assessment of the materials to be disturbed during the life of the mine, and in particular the dune materials deeper than 0.6 m is **highly recommended**.

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