DUST ABATEMENT IN THE GOLDFIELDS OF WESTERN AUSTRALIA

GOLDFIELDS DUST ABATEMENT COMMITTEE

1981

DEPARTMENT OF CONSERVATION AND ENVIRONMENT
BULLETIN No 86

DUST ABATEMENT IN THE

GOLDFIELDS OF WESTERN AUSTRALIA

PROGRESS REPORT FOR 1973 - 1981

AND SITUATION REVIEW FOR THE

GOLDFIELDS DUST ABATEMENT COMMITTEE

BY

THE DUST ABATEMENT TECHNICAL SUB-COMMITTEE

Compiled for the
Goldfields Dust Abatement Committee
by R.M. Nunn
Department of Conservation and
Environment
April 1981.
DCE Bulletin No. 86

PREFACE

The Goldfields Dust Abatement Committee (GDAC) was established with Cabinet approval in March 1973 and since that time it has been investigating the problem of dust abatement in the Eastern Goldfields of Western Australia. State Treasury provides 50% of the budget with an annual allocation in the order of $12,500, the balance being contributed by the mining industry (Kalgoorlie Mining Associates and Western Mining Corporation), the Shire of Boulder and the Town of Kalgoorlie.

Most of the abatement work is done under contract while the maintenance is carried out by an appointed ranger with assistance from the two local authorities. However the monitoring and technical input has been left to an informal Technical Sub-committee of the GDAC. By far the bulk of this work has been initiated by the regional officers of the State Departments of Agriculture and Forests; Mr. J.G. Morrissey and Mr. P.C. Richmond; with technical advice from CSIRO and officers of the State Department of Medical and Health Services.

In more recent times with referrals and requests for advice and assistance from other areas with similar dust problems, other personnel have become involved in the work being carried out by the GDAC, particularly that aimed at the stabilisation of mining waste (slime) dumps.

Besides the GDAC itself, other State Departments and Organisations which have been involved are :

C.S.I.R.O. - Division of Land Resources Management

Department of Agriculture

Forests Department

Department of Health and Medical Services

Department of Conservation and Environment.

Because of the high costs anticipated in stabilising the mining waste dumps and the need for much more work to be carried out before precise and guaranteed treatments can be recommended, there is an urgent need to review the work carried out to date in order that all the involved organisations are aware of the likely future commitments.

This work needs to be viewed in the proper context and it is appropriate therefore that it be considered together with all the other dust abatement work carried out by the GDAC at Kalgoorlie as well as with slime dump trials initiated elsewhere in the State. In this vein, this document has been prepared for the GDAC by the following authors as a complete Progress Report for 1973-1981.

Mr. J. Addison - Department of Agriculture

Mr. D.J. Carter - Department of Agriculture

Dr. J.K. Marshall - CSIRO, Division of Land Resources Management

Mr. J.C. Morrissey	-	Department of Agriculture
Mr. R.M. Nunn	-	Department of Conservation and Environment
Mr. R.A. Powell	-	Department of Health and Medical Services
Mr. J.R.H. Riches	-	Department of Agriculture
Mr. P.C. Richmond	-	Forests Department

R.M. Nunn
Department of Conservation and Environment
Perth, April 1981.

CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF PLANS

LIST OF PLATES

1. SUMMARY

Dust abatement work in Kalgoorlie has been carried out by the Goldfields Dust Abatement Committee since 1973. The work has been equally directed towards the three principal areas of dust generation. These are the unsealed areas within the Kalgoorlie and Boulder townsites, the sparsely vegetated pastoral properties adjacent to the town boundaries and the mine waste residue (slime) dumps to the east and south of Boulder.

In the first two areas, work is progressing at a satisfactory rate with tree planting and protective fencing programmes aimed at stabilising areas in the townsites and developing a system of greenbelts around the towns respectively. However abatement work has not been so successful on the third area, the slime dumps. Proven methods of slime dump stabilisation using either abundant supplies of fresh water or surface sealing treatments such as bitumen etc. have been used successfully elsewhere in Australia (e.g. Broken Hill).

However abundant fresh water is not available at Kalgoorlie while, with the large areas involved the proven surface treatments are either too expensive or short-term in nature to contemplate at this point in time. Stabilisation efforts on the Kalgoorlie dumps have therefore been directed to finding cheap, alternative methods using either local materials or plants indigenous to the area. Some limited success using a surface covering of stone fragments has been achieved but further work is required to understand the effect of controlling parameters before full-scale treatment can be endorsed. The appropriate treatment for the steep sides of some of the waste dumps continues to be an enigma.

The problem is not confined to Kalgoorlie and Boulder. Other mining centres in the arid zones of Western Australia have similar dust problems and enquiries of government have been made from several such centres (e.g. Bullfinch and Norseman). If the State is to be consistent in its approach towards environmental quality control in the mining industry, it should continue to support this work directed at the stabilisation of mining waste residues as well as maintaining its present statutory involvement in dust control through the Clean Air Act and the Mines Ventilation Board.

It is recommended that the State Government continue to provide moderate budgetary support to the present Goldfields Dust Abatement Committee in order that a successful method of stabilisation can be determined for dry slime dumps in arid areas of the State. This Committee is already established and is resident in the most appropriate regional setting. It has seven years of experience in tackling the problem. Furthermore, appropriate State Government Departments with relevant expertise should provide input into the research necessary to resolve the problem.

2. INTRODUCTION

Kalgoorlie as a mining town has always been dusty and concern for the dust problem, or at least its potential, was publicly expressed as early as 1898. However, in those days the major source of dust was from man's activities in clearing vegetation. This source of dust generation still exists but now there is another very major source of dust in Kalgoorlie; the old mine waste disposal dumps. Today there are approximately two dozen dumps in the Kalgoorlie/Boulder region which are not being used. This means there are some 475 ha. of dry dump surface which are subject to wind erosion and which are a major source of dust nuisance to the residents of the twin towns.

The problem is by no means confined to Kalgoorlie. There are many towns in Western Australia which owe their start to mining and which have an abandoned waste dump which is a continuing source of dust to the present residents of these towns. Bullfinch, Norseman, Leonara, Wiluna, Mt. Magnet to name just a few are all romantic names linked with the State's mining history. They are also all towns with serious dust problems directly attributable to unused mining waste dumps.

One factor common to all is that these towns are located in remote areas subject to very arid climatic conditions. Fresh water is a scarce commodity and in most cases the groundwaters have very high concentrations of total dissolved solids. Groundwater salinity levels in the Eucalyptus Zone of the Eastern Goldfields are in the order of 20,000 ppm or more. Samples taken from the Mt. Charlotte mine assay at 38,000 ppm chloride which is approximately twice the concentration of sea water. These natural groundwaters were used in the gold concentrating and extractive processes and consequently many of these waste residue dumps are highly saline. In some instances sulphide mineralization was present in the ore. Subsequent crushing, washing and exposure to the atmosphere has caused oxidation of these sulphides and a concomitant development of acid conditions in some of the dumps. Furthermore the very crushing process necessary for the extraction of the mineral wealth produces a waste product, commonly called slimes, which is both extremely small in particle size and relatively uniform in its size distribution. Samples analysed from Kleman's dump at Kalgoorlie showed that 82% of the dump consisted of fine sand and that 91% of the dump had a particle size of less than 0.2 mm[1]. *

These three factors of salinity, pH and a small uniform particle size all add up to the slime dumps being very poor growing mediums for plants. Elsewhere in the world (South Africa) and Australia (Broken Hill) similar mining wastes have been able to be stabilised by the establishment of vegetation on the slopes and tops of the dumps. This has only been possible because of the abundant supply of fresh water to leach the salts and acidity out of the top metre and so produce a relatively hospitable growing medium for some of the native plants adapted to the local climatic conditions.

If fresh water was available, it would be possible to do this at Kalgoorlie and other similar places in Western Australia. Plants such as the *Atriplex* ssp., *Maireana* ssp., *Arthrocnemum* ssp. and others readily exist in clay pan and salt lake environs in these arid areas. Further proof that this is possible is given in Plates 1 and 2. These are photographs of the slime dumps at the State battery at Kalgoorlie. This dump has been constructed using fresh scheme water and a reasonably effective, stabilising cover of native and introduced vegetation is evident. It is important to note that the native plants are self established from natural wind-blown seed.

* For reference, please refer to page 66.

PLATE 1 Native vegetation growing on the State Battery dump at Kalgoorlie.

PLATE 2 Introduced tamarisk trees growing on the State Battery dump at Kalgoorlie.

However, at Kalgoorlie/Boulder, and in most of the other West Australian localities with similar dust problems caused by unstabilised tailings dumps, an abundant supply of fresh water is simply not available. Furthermore, the areas involved are quite large (e.g. 475 hectares at Kalgoorlie/Boulder, 40 plus hectares in one dump at Bullfinch) and are subject to severe wind erosion. The "blasting" effect of the saltating sand particles moving over the dump surfaces would also make it more difficult for small plants to become established in this already inhospitable medium, as would other factors such as the extremely high summer temperatures and levels of solar radiation.

The Goldfields Dust Abatement Committee (GDAC) has been investigating the problem of dust abatement in Kalgoorlie/Boulder since 1973. Of all the principal source areas of severe dust generation, the mining waste residue dumps seem to be the most difficult to stabilise. Synthetic means of sealing the dumps (e.g. with bitumen) are available but with the areas and costs involved these are not realistic options. Other alternatives using vegetative means and the use of a 'rock mulch' have been investigated by the GDAC and it would appear that the anticipated costs of successful slime dump stabilisation are likely to be very high no matter what method is used.

The purpose of this report is to review all the slime dump stabilization work carried out to date in these arid areas of Western Australia. The objective in reviewing the results at this point in time is to provide a sound basis for all participating bodies (State, Commonwealth and local government, and the mining industry) to review their likely budgetary and staff commitments in the light of :

a) future research required, and

b) the possible costs of full treatment.

At the same time, this opportunity has been taken to report on all other progress by the GDAC from the commencement of its work in 1973 to April 1981.

3. HISTORICAL BACKGROUND

It would seem that Kalgoorlie/Boulder has always had a dust problem. The first recorded warning was an article in "The Kalgoorlie Miner" in 1898 which drew attention to the clearing of trees around the townsite. The timber was in heavy demand for underground mine supports and as a source of fuel, particularly for the distillation of water and later to drive the pumps for the Perth to Kalgoorlie water scheme.

Since the turn of the century interest in the dust problem has fluctuated in accordance with variations in seasonal conditions. In 1947 a Regeneration Committee was formed. However, it only met three times in the next two years and the scheme was abandoned in 1950 following good seasonal conditions. The Committee was reformed in 1958 but was never really effective.

Deteriorating drought conditions from 1969 caused a continual increase in the dust problem which culminated in a major dust storm on 6 October 1972. This particular storm caused a public outcry which resulted in official government recognition of the problem and a preliminary investigation was carried out by officers from the Departments of Mines and Agriculture.

In December of 1972, the Hon. Minister for Environmental Protection chaired a meeting to review the problem. A new committee was established to look into the matter and to report back to the Minister. This committee, consisting of representatives from Western Mining Corporation and the Departments of Agriculture and Forests, was required to define the major source areas of dust generation as well as to propose methods of dust abatement. The committee submitted its "Report on the Dust Problem in the

Kalgoorlie/Boulder Region"[2] to the Hon. Minister for Environmental Protection on 13 February, 1973.

This report identified the following three major source areas responsible for the dust problem in the Kalgoorlie and Boulder townsites.

<u>Source Area 1.</u> Unsealed, non-vegetated areas within the town boundaries. Most of these areas are disturbed by traffic and include road verges, service lanes and vacant Crown land (Plates 3 and 4).

PLATE 3 Bare road verge within the Kalgoorlie townsite.

PLATE 4 Unsealed service lane-way in Kalgoorlie.

<u>Source Area 2.</u> Those areas adjacent to the town perimeter which were the subject of grazing leases and unrestricted vehicle and livestock movements (Plate 5). Many of these areas were originally cleared during the early gold mining days. This includes the unsealed heavy haulage roads around the town perimeter (Plate 6).

PLATE 5 Overstocked grazing land adjacent to Kalgoorlie.

PLATE 6 Unsealed heavy haulage link road (Fimiston-Leonora) around the Kalgoorlie-Boulder perimeter.

<u>Source Area 3</u>. The old mine waste disposal areas (slime dumps) south-east of Kalgoorlie and Boulder (Plates 7 and 8).

PLATE 7 Aerial view of the slime dumps east and south-east of Boulder.

PLATE 8 Slime dumps under mildly windy conditions.

Following the recommendations of the committee's report [2], the Goldfields Dust Abatement Committee (GDAC) was established and the inaugural meeting was held on 13 March 1973. Mr. Julian Grill, now MLA for Dundas-Yilgarn, was elected as Chairman with Mr. Robin Peddie, the Boulder Shire Clerk, as Secretary. Other members came from :

Kalgoorlie Municipal Council

Boulder Shire

Chamber of Mines

Chamber of Commerce

Kalgoorlie School of Mines

Local Service Club

Local News Media

Department of Mines

Department of Agriculture

Forests Department

On 22 March 1973, the Hon. Minister for Environmental Protection submitted a Cabinet Minute requesting a special Treasury allocation of $10,000 for the GDAC for the remainder of the 1972/1973 fiscal year. The money was to be managed by the Department for Environmental Protection to maintain the impetus of the GDAC without prejudice to cost sharing in future years. Notice was also put forward that this should be an ongoing project with an approximate State allocation of $12,500 per annum for the next decade. Cabinet approved the Minute and the first dust abatement work (tree planting) commenced in autumn of 1973. Since that time, an active programme aimed at dust suppression in all three of these major source areas has continued to the present time.

4. GOLDFIELDS DUST ABATEMENT IN SOURCE AREAS 1 AND 2 SINCE 1973

The 1973 Report [2] recommended a variety of treatments for the major source areas of dust within the townsite and from the adjacent pastoral zones. The measures implemented to date are described below.

In 1978, the GDAC prepared a Progress Report [3] covering all work carried out from 1973 to June 1978. In December of 1979 this report was updated [4] and this Situation Review includes this latest work carried out on Source Areas 1 and 2.

4.1 Within the Townsites

4.1.1 Public Participation

The report by Richmond et al [2] recognised the importance of public participation in controlling dust within the town environs. Publicity campaigns were mounted to foster such cooperation and these were sponsored by the GDAC. Members of the GDAC were interviewed on both radio and television and in newspaper reports.

Public meetings were held and a printed brochure drawing all rate payers attention to the GDAC and dust abatement measures was distributed to all households in Kalgoorlie and Boulder. A "Dust Abatement Jingle" was developed for use on the local radio and television stations. In 1974 the Department of Conservation and Environment (then called Environmental Protection) prepared a public display which was made available for the Kalgoorlie/Boulder Community Fair in March of 1975.

Unusually high rainfall for the three year period of 1973-1975 allowed for the development of a dense cover of vegetation (grasses and weeds) over most of the unsealed areas within and adjacent to the townsites. This caused a reduction of dust generation within the townsite and a concomitant reduction in public interest and concern.

4.1.2 Woodchipping

In October of 1973, the GDAC purchased a woodchipping machine (Plate 9) and this machine has been made available to people and organisations wishing to produce their own wood chips. Materials used are tree loppings and waste sandalwood bark. The woodchip mulch technique is successful in both reducing dust and providing a moisture retaining cover to local gardens. However, due to the shortage of available material and the mechanical limitations of the chipping machine, it has not been widely used.

Western Mining Corporation has used woodchip mulching techniques with very successful results in the establishment of native gardens at Kambalda (Plate 10).

PLATE 9 GDAC woodchipping machine in action.

PLATE 10 Woodchips used as a mulch to help in the establishment of native gardens around Western Mining Corporation's office block at Kambalda.

4.1.3 Treatment of Laneways

Numerous techniques were recommended for the treatment of unsealed laneways within the townships. An emulsion was applied on a trial basis but proved to be unsuccessful.

The use of smelter slag as a blanket cover was investigated but local government engineers advised that :

a) the resulting loose surface would add to the risk of accidents and injury from "flying stones", and

b) it would not bind under vehicular traffic.

The permanent sealing of back lanes in Kalgoorlie/Boulder and the fencing of large unsealed areas within the townsites was recommended in the 1973 Report [2]. These measures have not been carried out to date due to the high costs involved.

4.1.4 Tree Planting

The 1973 Report [2] recommended the wide use of tree planting both as a dust abatement measure in creating windbreaks and as a method of improving the general aesthetic aspects of the many bare areas of land adjacent to and within the Kalgoorlie and Boulder townsites. Since the formation of the GDAC a total of 2200 trees have been planted within the townsites and regeneration zones. In spite of low rainfalls in 1976 and 1977, a 70% establishment rate has been achieved. Considering the harshness of the environment and the severe impact of vandalism, this tree planting programme must be regarded as one of the significant achievements of the GDAC.

A detailed description of the locations and numbers of the trees planted is given in Table 1 while some of the success achieved can be estimated by observing Plate 11. The trees have been obtained from Forests Department nurseries and have been comprised largely of eucalypts native to the dry Eastern Goldfields region. The most common species used have been _E. torquata_, _E. salubris_, _E. stricklandii_, _E. brockwayi_ and _E. dundasii_.

PLATE 11 GDAC tree plantings within the Kalgoorlie townsite area.

Table 1

GDAC Tree plantings 1973 - 1979.

Year	No. of Trees	Locations and Details
1973	1000	1. Adjacent to Kalgoorlie cemetery. 2. Gribble Creek area bounded by Burt and Ivanhoe Streets, Boulder. 3. Intersection of Lionel and Frank Streets,Boulder. 4. Powell Street, Boulder. 5. Intersection of Lionel, Ardagh and Roberts Streets, Kalgoorlie.
1974	300	All trees purchased were destroyed by vandals while in the Boulder Shire nursery.
1975	Nil	No planting.
1976	300	No. 1 regeneration zone adjacent to the south-west corner of the R.S.L. golf course and adjacent to the Ora Banda pipeline. The golf course area had been devastated by wildfire. The Ora Banda pipeline area was devoid of trees.
1977	300	Some of the 1973 areas were replanted. The Powell Street location had failed due to grazing by goats. An area east of Boulder Road near the Croesus treatment plant and an area bounded by Leonora Road and Outridge Terrace, were also planted.
1978	300	Boulder Block Road adjacent to the Hainault Tourist Mine. Also Hannan Street west of the PWD Store and an area adjacent to the Trans Australia Railway and south of the Regional Hospital
1979	300	Plantings were at lower Hannan Street, Burt Street (i.e. near Gribble Creek) and at the old Monte Cristo Quarry Site.
1980	965	1. In Zone 2B, near Parkeston; a total of 560 trees. 2. Powell Street, opposite the Boulder Station; 195 trees. 3. Gribble Creek area, 145 trees were planted in new locations with 65 refill plantings in old areas.

4.2 The Regeneration Zones

4.2.1 Fencing

The 1973 Report [2] recommended the fencing of vermin proof regeneration zones around the perimeter of Kalgoorlie/Boulder and the complimentary control of all grazing within a 10 kilometre radius of both townsites.

A number of regeneration zones were defined and their precise locations are shown on Plan 1. To date two major zones have been constructed, each with two separate parts.

The first, No. 1 Area, was commenced late in 1974 and was completed in mid 1975. This zone covers 1550 hectares and is surrounded by 22.5 kilometres of standard rabbit proof fencing. Immediately problems were encountered and most of these were associated with land tenure. A number of institutions, sporting bodies and individuals had either legal or traditional rights of tenure and/or access to much of the land proposed for Zone No. 1. The location of the fenced zone then became a compromise between what was technically desirable to achieve the objective of dust abatement and that which was able to be achieved in practice.

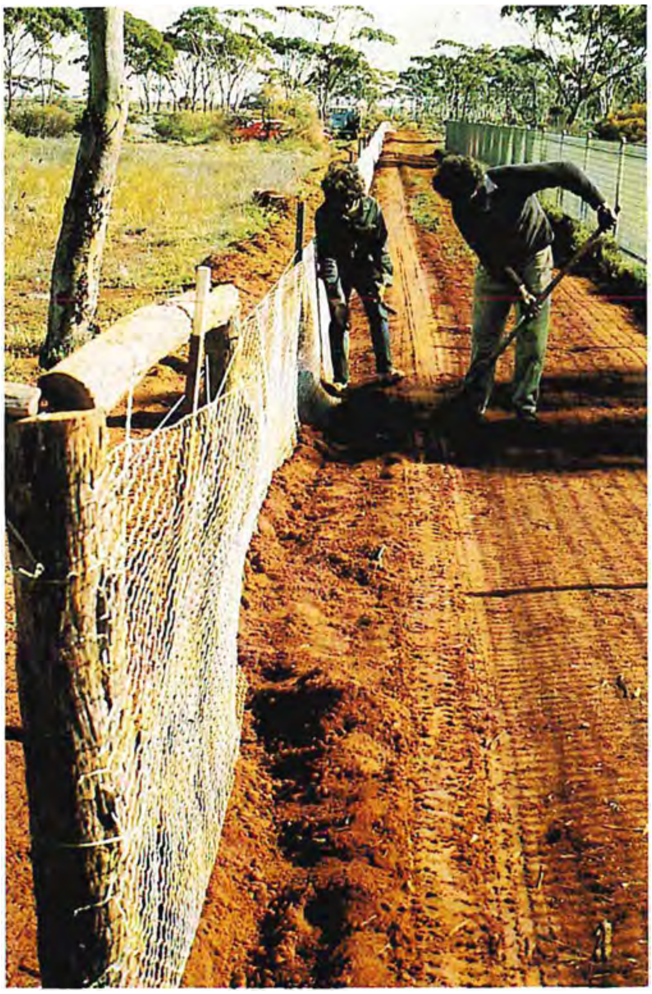


PLATE 12

Construction of access way through Regeneration Zone No. 1.

Zone No. 1 was constructed so that there was access through the area at three points (Plate 12). These are :

a) Along the Ora Banda pipeline track crossing the area from south east to north west. This track permitted continued access to the Kalgoorlie Town Council's gravel pit located in Zone 1.

b) Via Hawkins Street which provides access to both the Kalgoorlie rubbish pit and the Kalgoorlie rifle range which are both situated in Zone 1.

c) Via Graeme Street to the Telecom transmitter tower located on the outer boundary of Zone 1.

During construction there was a strong protest from people involved in horse sports as their traditional access to bush areas, now within the No. 1 Zone, had been curtailed. Discussion with the GDAC led to the provision of special gates at two points of access on both the inner and outer fences. These gates allow horses to be taken either through the zone to the bush areas beyond, or to two special exercise tracks within Zone 1.

Despite these attempts to have traffic restricted within the zone, there is more activity within this zone than is compatible with the objective of dust abatement. Vandalism to the fence was initially very high. It has now declined with time although there are still isolated instances where people cut the fence to gain access.

With the experience of Zone 1, the No. 2 Zone has been planned so that it will consist of five discrete enclosures which will be separated from each other by major roads, and from the No. 1 Zone by the Leonora railway line. The fences will be set back sufficiently from these roadways so as to allow ample recreational access to the bushland beyond the regeneration zones.

So far Sections 2A and 2B of the No. 2 Zone have been constructed using the same style of fencing as was used in Zone 1. Sections 2A and 2B respectively consist of 5.5 kilometres of fencing enclosing 160 hectares and 10 kilometres enclosing 500 hectares (see Plan 1).

It will be impractical to construct regeneration zones in the area between Zones 2B and 2C. Because of the existing and complicated tenure of land in this area, the fencing would have to be too distant from the townsite to be effective. Section 2C (see Plan 1) will consist of three separate sections. Construction should be completed during the 1980-1981 fiscal year. It is also proposed to further subdivide Zone 1 in order to facilitate better management and reduce vandalism.

Further areas to the south and south-west are proposed for fencing and the suggested locations are given on Plan 1.

4.2.2 Land Tenure

While the regeneration zones are vested with the two local authorities, they are not covered by local by-laws. Consequently the control of vandalism and non-complimentary forms of land-use in these areas is made difficult in the absence of penalties for trespass. Investigation of this matter is under review but it is complicated by the problems of existing tenure, land transfer and particularly the existence of numerous and different kinds of current mining tenements and authorised holdings approved, in these zones, under the Mining Act of 1904. Furthermore there is some reluctance to proceed with the adoption of such by-laws at this point in time on two accounts. Firstly, sections of the current Mining Act of 1904 may provide a defence against such charges on the grounds of the rights which this Act entitles to the holders of approved and current tenements and authorised holdings. Secondly, while the Mining Act of 1978 has been assented to, the Regulations to the Act have not been finalised and no one is sure how these regulations will affect the matter.

4.2.3 Grazing

The control of grazing in the areas adjacent to the townsites but outside the regeneration zones has been impossible to achieve. Freehold land and miners' homestead leases continue to be grazed to a state that they present a significant source of dust generation. Fortunately the dairies located on the perimeter of the townsites have closed and the 300 odd free ranging cattle present around the town in 1973 have been removed. Free ranging stock within or adjacent to the regeneration zones are now restricted to a few horses and goats with occasional itinerant sheep and cattle which stray in from adjacent pastoral leases.

4.2.4 Tree Planting

The 1973 Report [2] recommended that tree planting be carried out in the regeneration zones as well as within the townsites. To date some 300 trees have been planted in Zone 1 and a further 600 in Zone 2 during the autumn of 1980. The location and details of these plantings are given in Table 1. From 1980 on, it is proposed to increase the rate of planting to 1000 seedlings per annum of which approximately 60% will be in the regeneration zones and the balance within the townsite.

4.2.5 GDAC Ranger

On 2 April 1974, Mr. Laurie Turich was appointed by the GDAC as Ranger. The position was originally full-time and Mr. Turich carried out the initial fencing of Zone 1A. The current Ranger is Mr. Joe Houldsworth. The position is now part-time and the duties include patrols, inspections and repairs to the regeneration zone fences, and the collection and maintenance of the dust gauges on the slime dumps and throughout the townsites.

4.3 Dust Monitoring in Kalgoorlie and Boulder from April 1973 to January, 1977.

4.3.1 Location of Gauges

During the latter part of 1972, the Chief Health Surveyors of the Kalgoorlie and Boulder local authorities discussed with the State Public Health Department the matter of a dust monitoring programme for the Kalgoorlie/ Boulder area. Following these discussions the Public Health Department made twelve Central Electricity Research Laboratories (CERL) directional dust gauges which were sited at the locations listed below and shown on Plan 1.

Gauge No.	Location
1.	Great Boulder Mine
2.	South Kalgoorlie School
3.	East Kalgoorlie School
4.	Eastern Goldfields High School
5.	Boulder Central School
6.	South Boulder School
7.	Boulder Caravan Park
8.	West Kalgoorlie Freight Yards
9.	Kalgoorlie School
10.	North Kalgoorlie School
11.	Killarney Street, Lamington
12.	Elizabeth Street, Kalgoorlie

Monthly samples were collected from April 1973 to February 1977 and were sent to Perth for analysis by the Clean Air Section of the Public Health Department (now called The Department of Health and Medical Services)

PLATE 13

CERL dust gauge.

In the following section, results are expressed in units of "Total Dirtiness" which is a measure of the soiling effect of the particulate matter which is blown to the location on which the CERL gauge is sited. The CERL gauge collects dust from all directions in four collecting pots (Plate 13) which face north, south, east and west. The dust collected in each pot for a given time period (usually 1 month) is measured using an optical method whereby the amount of dust is computed from the amount of obscuration it causes to the intensity of a standard light path which has been previously calibrated. Results are expressed in units of obscuration.

The dust in the CERL gauges is collected from all directions facing towards a major source of dust. A correction is applied for that part of the sample period when calm conditions prevail.

4.3.2 Results and Discussion

The monthly dust results from all gauges are shown in graphical form on Figure 1. Results have been plotted in units of Total Dirtiness and have been plotted on a plan of the Kalgoorlie area to facilitate the interpretation of results relative to the township and the three major Source Areas of dust generation (see Section 3)

In considering the results, it is important to recognise that during the four year study period a large number of the CERL gauges were subject to instances of vandalism. Much of the data were lost by either physical damage to the gauges themselves or by contamination from foreign material being inserted into the gauges.

It is not yet possible to say what is the normal dirtiness or dustiness for an area such as Kalgoorlie. Obviously in good seasons the dust levels will yield low averages, even over several years, while in years of drought, dust levels could naturally be expected to be much higher. Furthermore it is reasonable to expect that one or two bad dust storms could dramatically affect annual average dust levels.

From the results of monitoring during 1973 to 1975, it is evident that these could be called "good" years. The results of the dust samples taken from sites in urban Kalgoorlie and Boulder can be compared with dust levels measured in Perth urban areas. Average dust levels, expressed in units of Total Dirtiness for the Perth urban area are :

Residential	0 - 3
Commercial	3 - 5
Industrial	5 - 10

At times, and only in the absence of the appropriate dust abatement practices, higher dust levels may be recorded near some industries such as quarries and cement work works. As a general rule dust levels in excess of 10 units of Total Dirtiness can be expected to result in public complaints. On this basis, the Kalgoorlie/ Boulder dust monitoring sites can be approximately grouped as follows :

Dust levels equivalent to Perth residential or commercial areas.

No. 8 West Kalgoorlie Freight Yards

No. 7 Boulder Caravan Park

No. 9 Kalgoorlie School

No. 10 North Kalgoorlie School

No. 5 Boulder Central School

Dust levels equivalent to industrial areas in Perth.

No. 11 Killarney Street, Lamington

No. 6 South Boulder School

Dust levels which would probably give rise to complaints of dust nuisance in the Perth metropolitan area.

No. 2 South Kalgoorlie School

No. 4 Eastern Goldfields High School

No. 3 East Kalgoorlie School

No. 12 Elizabeth Street, Kalgoorlie

No. 1 Great Boulder Mine.

Comparing the average dust levels measured over the three years, as shown in Figure 1, it appears that the highest dust levels are recorded on the east side of the town; probably reflecting the known major dust sources in the unstable slime dumps situated immediately east of the Golden Mile.

Figure 2 is a series of bar charts showing the average winter dust levels (April-September) compared to the average summer levels (October-March) for the period of 1973-1975 for each CERL gauge. As expected the greatest levels of dust are experienced in the dry summer months.

4.4 Dust Monitoring in Kalgoorlie and Boulder from 19 February 1979 to 4 March 1980

The GDAC recognised the need for an evaluation of the long-term effectiveness of dust abatement measures in the regeneration zones, the townsites and on the slime dumps (see Section 5). The only feasible method appeared to be the use of CERL gauges re-sited where possible on the same sites used during the April 1973-Febraury 1977 monitoring programme. Several new monitoring stations were also established outside the immediate township environs. The gauges were again set up and samples were collected from February 1979 to February 1980. The locations of the gauges and graphical representations of the results (in units of Total Dirtiness) are given on Figure 3.

For the purposes of comparison, some CERL gauge results from stations in metropolitan Perth and Pt. Hedland are included on Figure 3.

The dust levels within Kalgoorlie Townsite (CERL gauges 2, 5, 6, 7, 9, 11 & 12) are similar to Perth metropolitan commercial and industrial areas except for periods when strong north to north-westerly winds blow in the Goldfields. The gauges in the more eastern mining areas of Kalgoorlie, indicate dust levels similar to those experienced in Pt. Hedland adjacent to the iron-ore stockpile and shipping facilities. However results from gauges sited in the Goldfields range-lands generally simulate Perth resid ential and commercial areas; again with the exception of periods when strong north to north-westerly winds blow. These are the winds which cause the large dust storms in the pastoral regions of the Kalgoorlie-Yilgarn.

4.5 Conclusions on Dust Abatement in Source Areas 1 and 2

1. The greater part of the Kalgoorlie/Boulder residential area is subjected to dust levels which would not cause a serious dust nuisance during "good" years. However, the period April 1973 till January 1977 did not embrace any large dust storms although several major storms were experienced during October-November 1979.

2. Dust levels on the east side of Kalgoorlie and Boulder can be considered unacceptable when compared with levels in the Perth urban area.

3. The apparent source of the excessive dust levels measured on east side of the township is the slime dumps and the unsealed heavy haulage roads. This justifies considerable effort and expense to stabilise the dumps and prevent dust emissions from them.

4. A considerable area between the selected regeneration zones and within the township boundaries, is held as either mining tenements, authorised holdings or freehold land over which neither the local authorities nor the GDAC have much control. In toto these areas are sufficiently large as to create a major source area for dust generation.

5. There still exists a conflict in land-use objectives within the regeneration zones. For example the Town of Kalgoorlie currently operates a gravel pit within Zone 1 while the Shire of Boulder is sympathetic towards the development of a new quarry site in Zone 2C. These land uses are in conflict with the broad objectives of the regeneration zones and would significantly contribute to airborne dust levels.

6. At this stage it is envisaged that the present CERL dust gauge monitoring network will adequately assess the effectiveness of dust abatement measures adopted in Zones 1 and 2 (i.e. within the townsites and the regeneration zones respectively).

4.6 Recommendations For Future Dust Abatement Work in Source Areas 1 and 2

1. Major unsealed link roads pass through the second principal source area for dust generation: the town perimeter. To compliment the abatement objectives of the regeneration zones, it is recommended that these roads, such as the Fimiston-Leonora Road, should be either sealed or relocated.

2. It is recommended that tree planting at the rate of about 600 trees per annum, be continued in all regeneration zones as they are constructed. Contour bank and contour ripping to a depth of approximately 1 metre should be carried out in association with this planting programme.

3. Native seed from indigenous shrub species should be broadcast along the ripped contours.

4. Polythene mulching trials should be carried out in association with some of the tree plantings. Growth increments should be monitored to assess any additional benefits from increased soil moisture retention from the black polythene sheeting.

5. Fencing of the regeneration zones should continue as funds become available until such time as a permanent, effective green-belt is established around Kalgoorlie/Boulder.

6. Regeneration Zone 1 should be further subdivided to facilitate effective management of this single large area.

7. Consideration should be given to the development of an effective system of mining tenement referral from the Mines Department to the GDAC. The GDAC, through its Sub-committee is well backed up with technical knowledge and experience in the matters of soil erosion control and revegetation techniques. The GDAC should have the opportunity of recommending appropriate conditions of approval on tenements applied for within or between the regeneration zones. Such conditions, which could be listed as encumbrances at the time of approval, would be directed towards ensuring that dust abatement measures be adopted during the currency of the tenement, and that reasonable standards of rehabilitation be observed before relinquishment or surrender.

8. Professional legal advice should be sought on the matter of trespass and the control activities within the regeneration zones. The terms of reference for this review should include an assessment of the situation relating to mining and associated activities taking place under the current Mining Act, and the 1978 Mining Act and its presently Draft Regulations. The control of activities to these regeneration zones is seen as essential to the successful abatement of dust at Kalgoorlie/Boulder.

5. GOLDFIELDS DUST ABATEMENT IN SOURCE AREA 3 - THE SLIME DUMPS.

5.1 Background

The 1973 Report (2) in identifying the slime dumps as one of the major sources of dust, also emphasised their aesthetic and historical importance in the major traditional mining centre in the State. The authors of this report reviewed a wide range of possible treatments which could be applied to the slime dumps to reduce wind erosion. In tendering its recommendation the 1973 Review Committee proposed that proven chemical stabilising agents provided the best immediate short-term solution to controlling dust from the dumps. In particular the Committee recommended the use of a brand above all other such agents but due to the high cost, suggested that it should only be used on the most unstable of dumps. The Committee advised that Petroset could only be expected to control dust for 2-5 years and that the use of chemical bonding agents should only be regarded as an interim control measure.

In recognition of the short term value only of chemical stabilisation, the 1973 Review Committee also recommended that a research programme was warranted to solve the problems of long term erosion control of the mining residue dumps in the Kalgoorlie/Boulder area. The Committee advised that in formulating a research programme, the intrinsic aesthetic value of the dumps should be recognised and any long term control measures should take note of this important factor. Among other things it was recommended that the research programme be directed along the following lines.

1. An investigation of the physical and chemical composition of the slime dumps.

2. A thorough investigation of vegetative methods of stabilisation of the dumps. This should include an investigation of the factors controlling natural colonisation of old tailings dumps in the Eastern Goldfields.

3. Trials to investigate the use of physical and chemical stabilising materials.

4. An investigation into methods of removing or stabilising the large sand drifts surrounding the bases of the dumps.

5. An investigation into the use of sewage effluent.

5.2 Investigations on Short-Term Stabilisation

In 1973, six propriety lines of surface stabilising agents were all applied to trial plots located on the Trafalgar and another waste dump. At both locations these treatments showed no significant reduction in dust levels. Details of the size and treatment rates of these trials were not kept.

With application costs in the vicinity of $1000 per hectare in 1973, further use of such sealing compounds was not investigated. However a review of surfactants will be continued from time to time as new products are developed. Several materials are currently being investigated.

5.3 Vegetative Stabilisation

5.3.1 WAIT-AID Ltd.

The investigation of long term solutions to the stabilisation of the waste residue dumps commenced in 1974. WAIT-AID Ltd. was commissioned to investigate the factors influencing the natural colonisation of local tailings dumps and to advise on which plant species would be likely to be successful in developing a vegetative cover on the dumps. An area of approximately 40 square kilometres encompassing the majority of the shire dumps immediately east of the Kalgoorlie/Boulder residential area was selected and plant and soil samples were collected from most of the dumps. In its report (5), WAIT-AID reached the following conclusions :

1. Some 50% of the waste dumps within the study area were showing signs of primary colonisation.

2. Natural colonisation was more likely on the older, smaller, lower, less isolated and less steep dumps.

3. There were only minor differences in the overall chemical, physical and biotic characteristics of the vegetated and non-vegetated dumps within the study area.

4. There was no evidence of cyanide or toxic heavy metal contamination in the dumps.

5. The lack of colonisation on the bare dumps was due to the lack of :

   i) an available seed source,

   ii) sites for the seeds to lodge in on the bare, flat surfaces, and

iii) low availability of water. Run-off from the dumps was seen as a factor limiting the effectiveness of the meagre rainfall.

6. Chemical analyses suggested that fertilizers supplying nitrogen and phosphate will be required to ensure rapid plant establishment.

5.3.2 CBC Students

During 1975 and 1976 science students from CBC college, with the support of the GDAC carried out further investigations on the Kleman-Associated-Penrose-Trafalgar dump complex. Sample analyses indicated pH levels in excess of the mean of 7.1 as reported by WAIT-AID and were in the range of 8.0-8.5. This slightly alkaline level is common throughout the soils of the Eastern Goldfields.

Pot and field trials were also carried out by the students using material from the Penrose dump. Cereal species (mostly barley) and *Salsola kali* (Rolly Polly) were used. Results demonstrated that germination and plant growth can take place in mine wastes from the Trafalgar-Penrose group which is currently devoid of vegetation.

5.3.3 Field Plantings

In the winter of 1975, three areas were selected by the Forests Department for direct seeding trials using native tree and shrub species.

The seed from *Acacia graffiana*, *A. aneura*, *Eucalyptus ebbanoensis*, *E. stricklandii*, *E. transcontinentalis* and *E. campaspe* was sown during August in an old ash and mine waste dump located west of the Perserverance dump. A reasonable germination of both acacia species occurred but only two *A. graffiana* have since survived.

Direct seeding of acacia and eucalypt species has also been attempted on the remains of an old dump near the North Kalgurli treatment plant. The bulk of this dump had been removed for backfill and the site was deep ripped prior to planting in 1975. Fourteen *Acacia graffiana* plants have become established on this site as well as a reasonably dense cover of the saltbushes *Atriplex stipitata* and *A. vesicaria*.

Also during winter of 1975, a disused gravel pit in the No. 1 Regeneration Zone was ripped and sown with seed and 40 eucalypts and 40 acacias have become established as a result.

Seeds of the saltbushes (*Atriplex nummularia* and *Atriplex undulata*) and blue-bush (*Maireana georgei*) were planted during 1979 with and without superphosphate using the Mallen seeder on Chaffer's South, Perserverance and Associated dumps. No germination was observed.

As well as direct seeding, seedlings of a number of plant species have been sown. A total of 70 (35 Galenia secunda and 35 Atriplex vesicaria) were planted in the Penrose dump in 1977. Presently only two Galenias survive.

In January of 1978, saltwater couch runners were planted in contour channels on the Associated dump. After 4 weekly applications of water, these runners have become established and have spread slightly without any further hand watering. Also in 1978, forty Atriplex nummularia seedlings were planted along contours on South Chaffer's dump which had been fertilised with superphosphate at a rate equivalent to 250 kilograms per hectare. Seven of these plants still survive in 1980.

In May 1979 spinifex plants (Triodia sp.) were planted along a contour on the Associated dump. None have survived. In the following month eight tobacco plants (Nicotiana glauca) were planted in an adjacent contour and five of these are still growing. Also in June 1979 some seedlings of Eucalyptus oleosa var obtusa, Euc. griffithsii and Pittosporum phyllarioides, grown from seed collected adjacent to the dumps, were planted on the Associated and South Chaffer's dumps. These all failed to survive.

5.3.4 Contour Trials

In December 1976, Mr. J. Riches of the Department of Agriculture - Resource Management Division - visited Kalgoorlie to advise the GDAC on the control of run-off from the mine waste dumps. As a consequence of his visit, and using a Caterpillar 12E grader, a number of contour workings were thrown up on both a high and a low dump (the Perserverance and the Associated respectively). Some of the contours incorporate smelter slag while others consist solely of dump material. Segments of the contours were treated with either Vigran or superphosphate at the rate of 2 kilograms per 20 metres of contour furrow and small quantities of Atriplex stipitata and A. vesicaria seed were applied by hand to both dumps.

In August 1977, plant counts were taken along the contours and the results are given in Table 2. The figures for each treatment are the mean number of plants per metre of furrow recorded on 10 twenty metre replicates of each treatment. The figures only relate to counts from the low lying Associated dump. A few germinants were observed on the high Perserverance dump but by the time of actual recording, they had all perished. It is worth noting that these results were obtained after a dry winter in which only 45.6 millimetres of rain was recorded. Normal winter rainfall is around 120 millimetres.

In January 1978 plant counts were again made and this time the plants were classified into annuals and perennials. The results, which once again only apply to the Associated dump, are also given in Table 2. The major species to volunteer in the furrows was Zygophyllum. Others were

Atriplex stipitata, *Salsola kali* and *Maireana brevifolia*. Although more fertilizer was applied in the same fashion along the contours in 1978 and 1979, there was little new germination during either year.

Table 2

Plant Germinations in the 1977 and 1978 Contour Trials

Mean No. of plants per metre of contour furrow		Vigran	Superphosphate	Control
1977	Not classified	1.75	3.79	0.44
1978	Annuals	0.45	1.98	1.36
	Perennials	0.02	0.23	0.05
	Total	0.47	2.21	1.41

5.3.5 Fresh Cultivation

Another area on the Associated was cultivated by hand in 1979 to produce a broken, clod-strewn surface. Fertilizer was applied and seed bearing litter from adjacent rangelands was distributed over both cultivated and non-cultivated dump surface which had been fertilized. Visibly significant germination occurred on two occasions during 1979 on the cultivated plot, however the absence of follow-up rains caused a significant reduction in the establishment of these plants.

In comparison there was minimal germination on the uncultivated ground or along the original contours. It would appear that cultivation provides niches for the seed to lodge in and that, through time and with surface erosion and slumping, the availability of these niches is reduced with a concomitant reduction in plant germination. It is likely that this explains the decreasing germination rate since 1977 along the original contours on the Associated dump.

5.3.6 The Physical and Chemical Characteristics of the Slime Dumps

The physical and chemical characteristics of the mining waste material essentially determine the erosional behaviour of the dumps and the growth of plants on their surfaces. In an effort to determine some of these parameters, a number of soil samples were collected from several slime dumps, some on 24 November 1976 and the remainder twelve months later on 11 November 1977. The locations of the sampled dumps are shown on Plan 1. The samples were analysed for pH, salinity and moisture retention. Previously in June 1973, four other dumps were sampled and a particle size analysis carried out.

5.3.6.1 Particle Size Analysis

The results of the particle size analysis are given in Table 3 below. Results are for one bulk sample collected from each of the first four dumps sampled in June 1973 and one from South Chaffer's collected in June 1980.

Table 3

Particle Size Analysis of Slime Dumps

Size		Percentage of Sample				
Descriptive	Actual (mm)	Klemans	Perserverance	Lady Betty	Croesus	S. Chaffers
Coarse Sand 2.0 - 0.2	< .211	10.2	-	3.3	1.5	7.3
Fine Sand 0.2 - 0.02	.152-.211	15.6	2.7	1.5	6.1	8.6
	.105-.152	18.0	3.7	1.7	5.7	10.2
	.076-.105	24.8	11.3	11.9	18.1	9.3
	.045-.076	5.9	19.4	13.1	11.8	9.4
	.034-.045	2.9	5.8	7.9	5.4	6.6
	.024-.034	3.5	8.0	11.8	8.8	4.8
	.016-.024	3.6	8.8	11.8	8.2	4.4
Silt 0.02-0.002	.012-.016	2.7	7.1	7.2	6.3	1.7
	< .012	12.8	33.2	29.8	28.1	37.7

NOTE It is thought that variation between the dumps reflects firstly the age of the dump and the concomitant increase in milling efficiency the more recent the dump; and secondly differing mineralogy of the different ore-bodies worked.

Analysis below the size of 0.012 millimetres was not carried out so it is not certain what proportion of the slime dumps material would fall into the descriptive class referred to as "clay" - i.e. less than 0.002 millimetres.

Several observations are worth noting. Firstly the bulk of the material consists of fine sand-sized particles (i.e. between 60-70%) and as such is available as material to saltate and cause sand-blast (see Section 5.4). This very high proportion of fine sand is reflected in the moisture retention characteristics of the material.

Secondly, it is generally accepted that particles up to 0.1 mm can be held in suspension as airborne dust under strong wind conditions (see Section 5.4). It is noteworthy that, apart from Klemans, up to 70% of the slime dump material falls into this category.

5.3.6.2 Moisture Retention Analysis

Moisture retention analysis has been carried out on a number of samples taken from five different slime dumps. The results, taken from the 1979 GDAC Progress Report [4], are given in the following Table 4.

Table 4 Moisture Retention Characteristics of the Kalgoorlie Slime Dumps

Dump	Total Moisture - % wt. for wt.			Water Available for Plant Growth (1/10 atmos - 15 atmos) i.e. gms H_2O per 100 gms soil
	Field Capacity i.e. 1/10 atmos	1/3 atmos	Permanent Wilting Pt. i.e. 15 atmos	
GMK	36.7	34.4	4.2	32.5
Associated	31.1	28.4	4.6	26.5
Klemans	31.4	28.7	3.6	27.8
Chaffers W.	31.3	28.2	3.8	27.5
Chaffers S.				
at 0-5 cm	39.4	34.1	7.5	31.9
at 25-30 cm	40.4	38.8	7.6	32.8

The moisture tension analyses show that most water in the slime dumps is held at low tension. Consequently it can be expected that the dump material will dry out readily thus posing, without some form of irrigation, possible problems for sustained plant growth.

5.3.6.3 Salinity and pH

On a number of occasions, samples of slime dump material have been taken from different localities and analysed for pH, sodium chloride content (% NaCl) and total dissolved salts (% TDS). The NaCl determinations have been by titration and the TDS results by resistivity methods. Two samples have been taken from each sample spot; a surface sample from 0-2 or 0-5 centimetres and a deep sample at either 14-16 or 25-30 centimetres. Complete results are given in Tables V and VI of the 1979 GDAC Progress Report [4] while the means are given in Table 5 below.

Table 5 Salinity and pH of the Kalgoorlie Dumps

Dump	Profile Interval					
	0 - 2 cms			14 - 16 cms		
	pH	% NaCl	% TDS	pH	% NaCl	% TDS
Associated	8.3	0.45	1.44	8.3	0.65	1.54
Klemans	8.6	0.06	0.36	8.71	0.09	0.38
Chaffer's W.	8.5	3.41	3.37	8.7	0.89	1.13
GMK 2	8.4	0.07	0.80	8.7	0.03	0.31
	0 - 5 cms			25 - 30 cms		
Chaffer's S.	-	-	1.61	-	-	1.03

The pH of the Kalgoorlie dumps tested seems remarkably constant with a maximum range of all samples from 8.1 - 8.7 which accurately reflects that found by the CBC students (8.0 - 8.5; see Section 5.3.2). This slightly alkaline range is quite common in soils of the Eastern Goldfields and will not present any problems to endemic plant species.

However salinity is more variable both between different dumps, and between the surface and at depth within the same dump. Chaffer's West is the most saline of all tested with a maximum surface salinity of up to 3.54% NaCl (6.12% TDS) and a mean of 3.41% NaCl. Chaffer's South is also very saline with a mean surface value of 1.61% NaCl. Mean surface salinity values on the other dumps tested range from 0.06% NaCl on Kleman's to 0.45% NaCl on the Associated.

Salinity at depth is less than at the surface in all dumps tested except the Associated and in many cases is well within the generally accepted range which some of the endemic species can tolerate. On the other hand surface salinities are sufficiently high on all dumps, except perhaps Kleman's (i.e. greater than 0.5% TDS) to suggest that germination of endemic species such as saltbush (*Atriplex* sp.) and blue-bush (*Maireana* sp.) may be inhibited. However once established with deep roots, the plants may survive.

5.3.7 Conclusions

From the work carried out to date, the following conclusions can be drawn on the matter of vegetative stabilisation of the slime dumps at Kalgoorlie.

1. Salinity levels are very variable and rather high in some of the waste dumps. This is likely to cause problems in successful plant germination. However salinity generally seems to decrease with depth to levels which may sustain the growth of some endemic species once deep root systems are established.

2. Soil pH appears to be slightly higher in the dumps than originally suggested in the WAIT-AID Report (5), however it is still in the range of 8.3 - 8.7 and this should not cause any problems to plants indigenous to the Eastern Goldfields.

3. The soil moisture characteristics of the dumps tested shows that most of the soil water is available well below 15 atmospheres moisture tension (i.e. permanent wilting point). This indicates, particularly with the normal hot and dry summer conditions, that the dump material will readily dry out and may pose problems for the survival of perennial plant species.

4. Particle size analysis of the slime dumps indicates that some 70% of the material consists of fine sand between 0.2 and 0.02 of a millimetre. Sandblast under windy conditions is likely to be a significant factor affecting the survival of small seedlings.

5. The smooth surfaces of the slime dumps do not provide adequate sites for the lodgement and collection of wind-blown seeds from adjacent vegetated areas. Furthermore the tops of many of the dumps (e.g. Chaffers, Perserverance, etc.) are

high and are probably above the range of most wind-blown seed.

Contour banks on the surface of the dumps prevent run-off and provide suitable sites for seed catchment and plant establishment. Similarly cultivation of the bare surfaces also provides sites for seed catchment and so enhances the chances of successful plant growth.

6. Both plant establishment and survival are enhanced by the application of fertilizers. The dump material, by virtue of its origin, is low in available nutrients. Of the fertilisers tested, superphosphate showed the best results.

5.4 Slime Dump Stabilisation Using a Stone Roughness Element

5.4.1 Basic Principle

In 1974 Dr. J.K. Marshall approached the GDAC with a proposal that dust generation from the mine residue areas could be reduced by the application of a roughness element to the surface of the dumps. Details of Dr. Marshall's proposal are given in the paper by Marshall, Morrissey and Richmond (1).

Briefly, and in simple terms, the basis of the proposal was to reduce the wind velocity at the surface of the slime dumps to below the threshold required to cause the saltation of sand sized particles. Without the force of impact of saltating (i.e. bouncing) sand particles, fine particles less than 0.1 mm would not be able to be forced out of the layer of laminar air-flow approximately 0.05 mm in thickness and into suspension in the atmosphere as air-borne dust. In theory "the wind force on an erodible surface is reduced to a negligible amount by a discontinous covering of non-erodible material depending on the drag coefficient of unobstructed elements of the material and on the geometry" of their placement on the erodible surface (1).

In effect, earlier works published by Dr. Marshall in 1971 (6), 1972 (7) and 1974 (8) indicated that arrays of non-erodible surface on average about 3.5 times their height apart, should reduce the average wind force at the erodible surface to a negligible amount.

These theoretical considerations formed the basis of Dr. Marshall's hypothesis which was tested on a small trial basis from 1975 to early 1977. This trial is discussed briefly in the following section and in detail in the paper by Marshal et at (1). An obvious potential benefit of the proposal was the fewer the rock fragments used, the cheaper the stabilizing treatment.

5.4.2 Stone Mulch Trials and Large Scale Application

5.4.2.1 Trials

In Dr. Marshall's trials, four treatment plots, each 25 x 50 metres were laid out on Kleman's dump with the long axis pointing directly towards the Boulder residential area. Rock fragments (mine mullock with an average diameter of 4 centimetres) were spread at varying densities over the trial area (Plate 14).

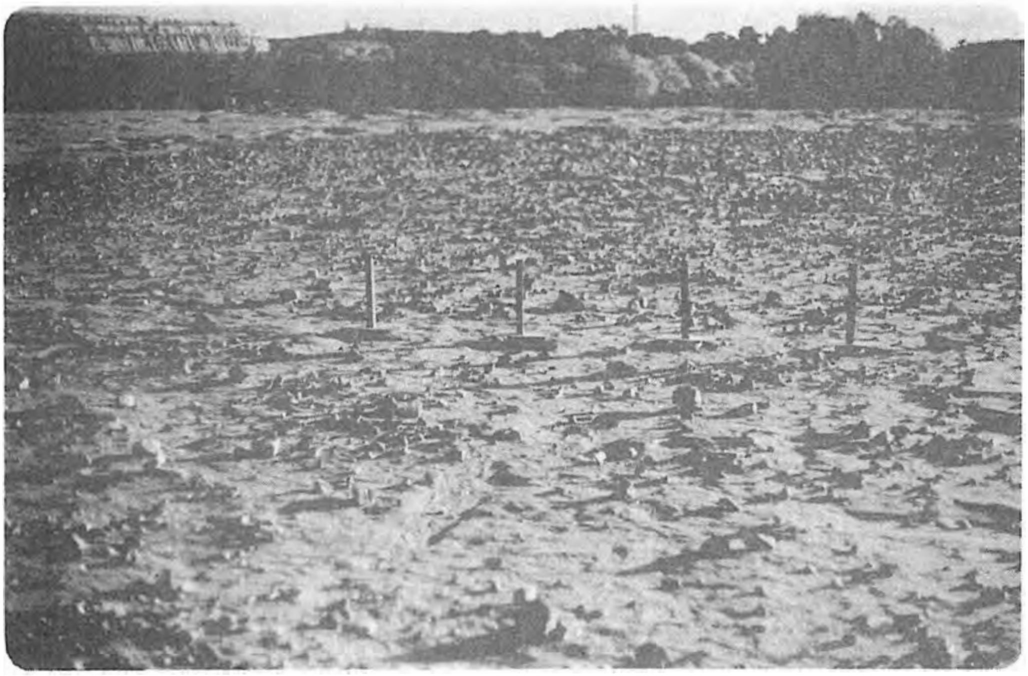


PLATE 14 Mullock laid out on the original trial area at Kleman's dump.

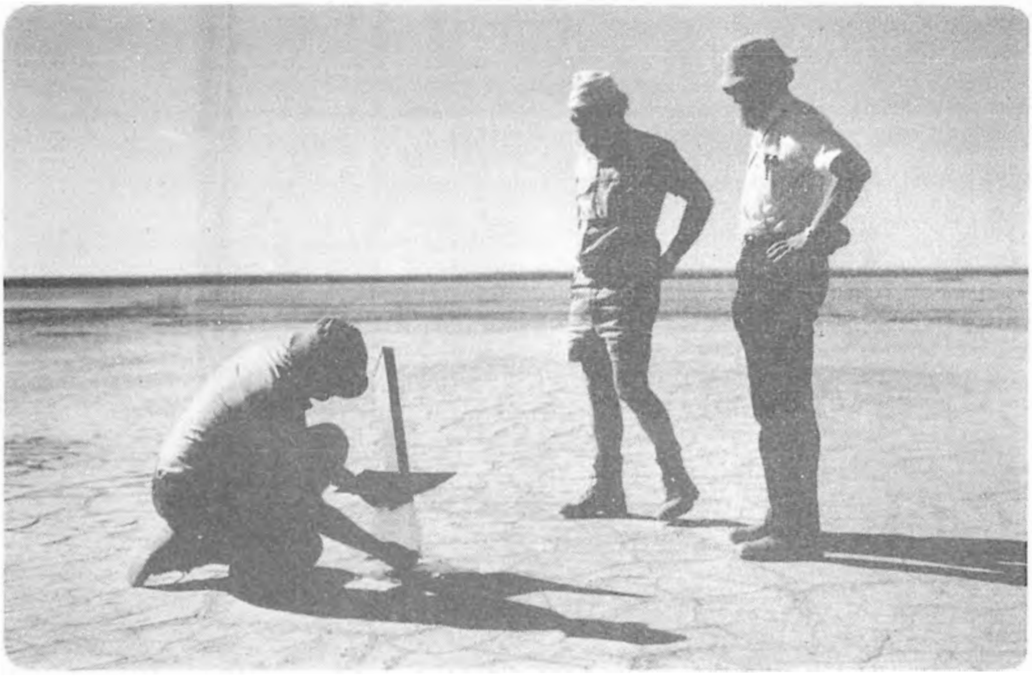


PLATE 15 Saltation gauge. Note plastic collection bag fixed to base of gauge.

The effects of the treatments in reducing soil (sand sized) movement across the dump surface were monitored by the use of uni-directional soil collectors (saltation gauges) designed by Dr. Marshall (Plate 15). A control untreated area was also monitored and the complete trial area was similarly monitored prior to treatment to ascertain any variability in the surface material. Samples were periodically collected, dried and weighed. The experiment, including the pre-treatment monitoring phase, was carried out from December 1975 to February 1977.

5.4.2.2 Large Scale Treatment

On the basis of the results from the trial area (see Section 5.4.3), and after an initial pre-treatment monitoring period using the same unidirectional soil movement gauges, large scale treatments using rock fragments of 4 centimetre minimum diameter (railway ballast) were applied to some 14 hectares of the surface of Chaffer's West dump (see Plan 1) in February of 1977. The treatments were applied at the theoretical rate of 40 tonnes per hectare using a Michigan road scraper.

The total cost of this treatment, including purchase of materials, plant hire and operator time was $784 per hectare.

Unidirectional soil movement gauges were sited on the treated surface and on an untreated control section of the dump. Samples were collected periodically and sent to CSIRO in Perth for drying and weighing. The total period of monitoring, including pre-treatment, was from September 1976 to April 1978.

At the same time 9 CERL dust gauges were set up around the edge of Chaffer's West dump(Plate 16) in an attempt to quantitatively assess any reduction in airborne dust levels resulting from the application of the stone fragments. The gauges were sited in positions chosen to best reflect changes in dust levels resulting from the treatment. Pretreatment readings were taken and compared with readings taken after the application of the rock material. The results for all 9 gauges, expressed in both weight of dust collected and obscuration units are given in Tables 6 - 14, a discussion of these results can be found in the following Section 5.4.3.2.

In May 1977 a second field scale treatment of rock fragments was applied to the Chaffer's East dump. Rock fragments of 4 centimetre minimum diameter (i.e. railway ballast)were applied using a road scraper, at a rate of 40 tonnes per hectare. The overall cost including materials and application was $557 per hectare.

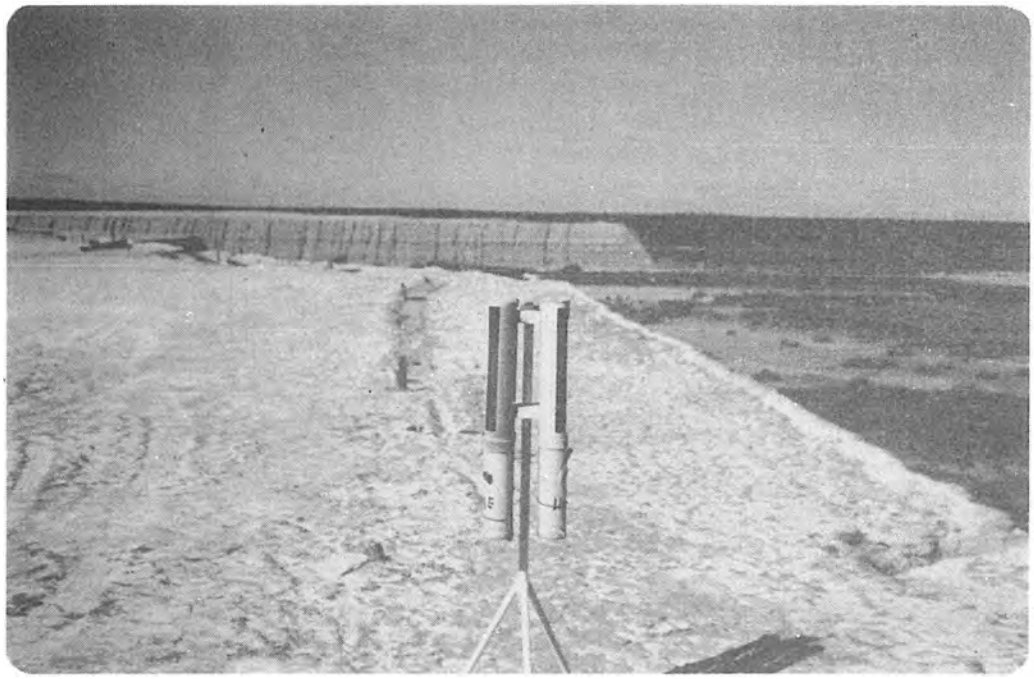


PLATE 16 CERL gauge as installed on Chaffer's dump.

Later in December of the same year the 36 hectare surface of the South Chaffer's dump was treated. The surface of this dump was so uneven that it had to be graded in order to enable machinery to work at normal operating speeds. Contour banks were constructed at half metre intervals and 4 centimetre railway ballast was again applied at a theoretical rate of 40 tonnes per hectare. The total cost of all treatment was $563 per hectare.

However for a number of reasons which are explained in detail later (see Section 5.4.4.1) the application of the rock fragments was very irregular and there were many areas where the theoretical spacing of 3.5 times, or less, the minimum diameter of rocks was not achieved. Because the spacing of the roughness elements is critical to the success of the treatment, 12 hectares of the dump had to be retreated. This required the application by hand of a further 296 tonnes of ballast at an additional cost of $385 per hectare over all. The final treatment cost on Chaffer's South was therefore $948 per hectare.

5.4.3 Results

5.4.3.1 The Effectiveness of a Roughness Element in Reducing Soil Movement (Saltation)

The effectiveness of the stone mulch treatments in reducing saltation was determined by comparing the amount of wind blown material caught in the saltation gauges situated on the treated areas, to that collected in the gauges located on the untreated control plots. It was also possible to measure the depth of material lost from the dump surface within each of the treatments.

On the trial area at Kleman's, Dr. Marshall's initial work indicated significant reductions in saltation after the application of a stone mulch. A summary of the results is presented in the following Table 15 while complete results are presented as Appendix 1 at the end of this report as well as in the paper by Marshall et al [1] and the 1979 GDAC Report [4].

Under conditions of moderate to high soil movement (i.e., moderate to strong wind strength), reductions of 60 - 70% saltation were recorded from these tables.

Table 15 Effectiveness of Original Stone Mulch Trials on Klemans

Treatment	Reduction in saltation March 1976 to March 1977	Depth of material lost November 1975 to March 1977	Reduction in material lost Between November 1975 and March 1977 as % of untreated control
Surface covered with continuous array of rocks. Inter fragment distance is 3.3 x mean fragment diameter Drag coeff= 0.4	75%	0.7 cms	ie $\frac{(2.1 - 0.7)}{2.1}$ x 100 = 67%
1/3 of surface covered in strips with arrays of rocks similar to above	37%	1.0 cms	51%
Surface covered with a continuous array of rocks at a more sparse rate than above. Drag coeff= 0.8	22%	1.5 cms	30%
1/3 of surface covered in strips with arrays of rocks at drag coeff = 0.8	3%	1.8 cms	15%
Control Nil Treatment	0	2.1 cms	0

Mean weights of saltating material collected from the large treated and untreated areas at Chaffer's West are given in Table 16. The percentage reductions in saltation are also given for each sample period. Complete results are given in Appendix 1 and in the 1979 GDAC Report [4].

Table 16 Mean Weights of Saltating Particles Collected from the Treated and Untreated Areas on West Chaffer's. (Weight in grammes)

Collection Date	Mean Wt. of Collection		% Reduction of Saltation
	Untreated Dump	Treated Dump	
16th Feb. 1977	425	42	90%
22nd Feb. 1977	295	47	84%
25th Feb. 1977	502	134	73%
5th March 1977	572	135	76%
26th Sept. 1977	8	4	50%
11th Dec. 1977	110	81	26%
23rd Jan. 1978	119	64	46%
10th March 1978	361	126	65%
27th April 1978	142	12	92%
23rd Sept. 1978	64	27	58%
7th Oct. 1978	11	6	45%
25th Oct. 1978	33	9	73%
8th Nov. 1978	441	185	58%
22nd Nov. 1978	11	4	64%
6th Dec. 1978	4	1	75%
20th Dec. 1978	65	36	45%
24th Jan. 1979	112	156	-39%
2nd March 1979	No figures available		
2nd April 1979	16	12	25%
27th April 1979	11	10	9%
6th July 1979	16	10	25%
27th July 1979	22	15	32%

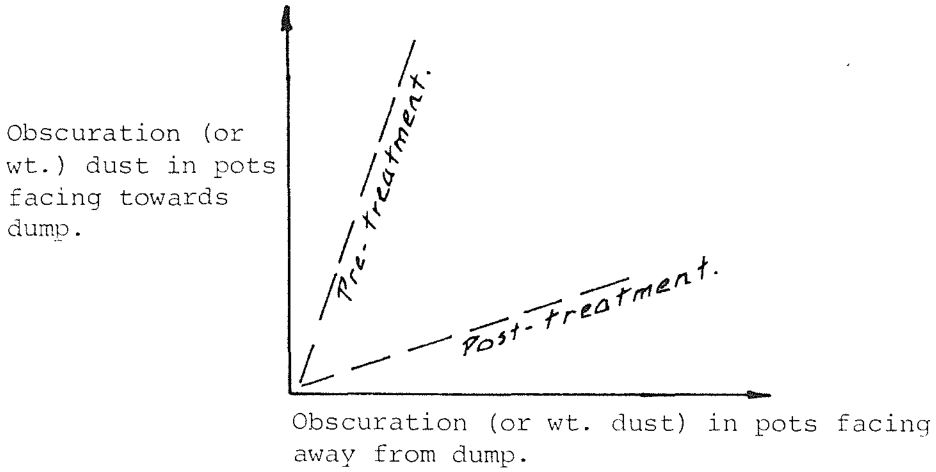
In the initial stages very good stabilisation was achieved with a reduction of saltation up to 92%. Later samplings have given variable results and have shown the effect to be much more complicated than was originally envisaged. In general the effectiveness appears to have decreased with time and in one instance a negative result was recorded. It is thought that a major factor reducing apparent effectiveness is the introduction of wind-blown sand from sources outside the treated and untreated areas. For instance, many of the slime dumps have large deposits of unconsolidated sand against the sides of the dumps. These piles of sand could provide a continuous source of "sand-feed" under windy conditions. Experimental design and the techniques of treatment application are also thought to be the cause of some of this unpredicted variability. These matters are addressed in detail in the following Discussion; 5.4.4.

5.4.3.2 The Effectiveness of a Roughness Element in Reducing Airborne Dust

The whole basis for Dr. Marshall's stone mulch treatment is that by reducing the amount of saltation, so the force available for generating airborne dust is also diminished. Consequently a reduction in soil movement across the surface of the slime dumps should show a concomitant reduction in airborne dust levels coming from the dumps. To test this a number of assessments have been made using the results of the CERL gauge sampling carried out on Chaffer's West. These are discussed below.

1. Comparison of Obscuration and Weight of Dust Collected From CERL Pots Facing Towards the Slime Dumps with those Facing Away from the Source

   If the application of a roughness element to the surface of the slime dump was effective in reducing airborne dust, it was assumed that treatment would have the following effect.



   The results of such comparisons for all pots facing towards the dump and all pots facing away from the dump, for all 9 CERL gauges, are given in Figures 4 and 5 (obscuration and weight of dust respectively). As can be clearly seen, there are no obvious trends indicating the anticipated regressions.

   To test this same matter further, members of the GDAC examined plots of the same results for each individual gauge before and after treatment. The members could not detect any trends indicating the expected reduction of dust after treatment. These graphs have not been included in this report.

Possible reasons for this lack of the expected correlation are discussed in detail in Section 5.4.4.

2. <u>Comparison of Obscuration and Weight of Dust, Before and After Treatment, Incorporating Adjustments Made for Wind Direction.</u>

One of the possible causes for the masking of any obvious correlation in the previous section may be due to the collection of dust from all points of the compass rather than just those winds which blew in the direction of the CERL pot facing the slime dump. This would include dust from adjacent untreated slime dumps as well as interference from the treated dump itself.

To check this, three hourly wind observations from the Kalgoorlie airport, supplied by the Bureau of Meteorology, were extracted and summarised for the pre-treatment (11 August 1972 to 22 January 1977) and post-treatment (9 May to 29 November 1977) periods for the full scale operations on West Chaffer's dump. Complete percentage direction frequencies are given in Table 17.

Additionally the rainfall during each period the dust gauge was exposed, the longest period without rain, and the average wind speed for the direction relevant to a particular gauge were also extracted. The obscuration and weight of dust collected during each period was corrected to determine the theoretical result if the wind had blown in that direction all the time. This assumption is only made to ease any comparisons of results before and after treatment.

All of this information, pre and post-treatment, has been tabulated for the inward facing pots only of CERL gauges 2, 6 and 8 (see Tables 18 to 20). Again it is impossible to extract any obvious relationship indicating a decrease in airborne dust levels after full scale treatment. It is concluded that dust from the surrounding untreated dumps (see Plan 1) caused interference and possibly obscured any effect of dust reduction from the treated area.

3. <u>Obscuration and Size Distribution of the Airborne Dust</u>

It was generally agreed that changing surface conditions or strong and variable winds could produce corresponding changes in the particle size distribution of the wind-blown dust being monitored by the CERL gauges. Obscuration per milligram of dust can be expected to increase as the size distribution of the collected dust tends towards smaller sizes. Alternatively the ratio of obscuration to dust weight will increase if the particle size of the dust collected decreases.

From the results in Tables 6-14, the ratios of obscuration to dust weight were calculated for each directional CERL gauge pot for the 20 month period which the 9 gauges were stationed on Chaffer's West. It was expected that there would be a change in the size distribution of dust being blown off the slime dump and that this change may reflect seasonal changes and variations in wind velocity. Furthermore it was felt that the application of a surface roughness element would reduce surface wind velocity and, in agreement with Dr. Marshall's hypothesis, only fine dust would be generated, even in moderately strong wind events. Accordingly the size distribution of dust collected after treatment should decrease compared to dust collected prior to surface treatment.

The obscuration to weight ratios were plotted for six CERL pots facing inwards towards the treated slime dump. The pots selected were the east facing pots of gauges 1, 7 and 8 and the north facing pots of gauges 4, 5 and 8. The resulting graphs showed no detectable trend towards a change in particle size before and after treatment and have not been included.

As a further test, the obscuration to weight ratios for the inward facing pots of CERL gauges 1, 6 and 8 were plotted and compared to the same ratios for all other pots combined of the same gauges. Again no obvious difference was detectable.

Finally, statistical analyses of :

i) the total results from all gauges,

ii) the total results on the basis of the 4 compass directions in which all CERL pots face, and

iii) on the basis of the results for each gauge:

were undertaken and the results are given in the following Tables 21-23. Results indicated that the obscuration to weight ratios were random with no distinct trends evident.

Table 21 Analysis of All Obscuration to Weight Ratios for All CERL Gauges

Mean	0.854
Std. Dev.	0.5179
X min.	0.07
X max.	3.63
Range	3.56

Table 22 Analysis of Obscuration to Weight Ratios By Principal Wind Direction (Average for all 9 Gauges)

	West	South	East	North
Mean	0.784	0.880	0.893	0.868
Std. Dev.	0.463	0.627	0.513	0.460
X min.	0.07	0.11	0.19	0.19
X max.	3.63	3.52	3.25	2.66
Range	3.56	3.41	3.06	2.47
N	110	102	105	112

Table 23 Analysis of All Obscuration to Weight Ratios for Each CERL Gauge

Gauge	1	2	3	4	5	6	7	8	9
Mean	0.934	0.688	0.704	0.769	0.780	0.851	0.943	0.896	1.130
Std. Dev.	0.490	0.331	0.508	0.578	0.421	0.353	0.670	0.452	0.616
X min.	0.15	0.19	0.22	0.23	0.11	0.28	0.25	0.07	0.38
X max.	3.25	1.73	3.33	3.52	1.93	2.38	3.51	2.16	3.63
Range	3.10	1.54	3.11	3.29	1.82	2.10	3.26	2.09	3.25
N	50	47	48	49	50	42	49	46	48

From the above analyses it was concluded that there has not been a noticeable change in the size distribution of dust collected, and therefore generated, before and after treatment of the slime dump surface. It is thought that the large range in the obscuration to dust weight ratios indicates a large variation in the size distribution of the dust collected and that this variation is due to the random variation in wind strength.

5.4.4 Discussion

The application of a stone roughness array to the surface of dry mining waste residue dumps at Kalgoorlie can be shown to reduce the movement of sand-sized particles across the dump surface. The amount of reduction is variable. From the trials carried out it is likely that wind-blown sand from outside the treated areas (particularly from the sand piled against the steep sides of the dumps) is a major cause of this variability. The effectiveness with which the stone mulch reduces saltation appears to decrease with time. Monitoring of airborne dust levels before and after treatment failed to elicit any direct correlation between saltation and dust generation, or any measurable reduction in airborne dust levels. Possible reasons for the lack of an obvious correlation are many and fall into the following two categories.

5.4.4.1 <u>Sampling Methods and Ineffective Experimental Design</u>

1. The time-base used for the sampling of the CERL dust gauges did not coincide with that used for the saltation gauges. Table 24 shows the sampling periods for the dust gauges compared with the saltation gauges.

   This was an elementary and unfortunate oversight and in order to correct this error the same trials were repeated on the Chaffer's West dump from 8 November 1978 to 24 January 1979. The results expressed as weight of dust in milligrams and as units of obscuration are given in Tables 25 and 26 respectively.* During this period the dust and saltation monitoring was carried out on the same time-base to ensure that the data were directly comparable. The results were again analysed using a variety of graphical and statistical techniques and once again there was no apparent correlation between airbourne dust and saltation.

2. Wind blown dust from adjacent untreated dumps would undoubtedly have been collected in the CERL gauges and so caused a contamination of the samples.

3. In hindsight it is felt that the CERL dust gauges mounted on the edge of the treated dump were probably too close to the dust source. Localised eddy systems around the gauges themselves, and willy-willys over the dump surface could have swamped the gauges with source dust, even perhaps depositing it unevenly in individual pots, thus negating the objectives of the monitoring.

   Also with the CERL gauges mounted on the edge of the dump, dust generated from the untreated steep sides of the dump could be caught in the pots causing further interference to the results.

4. It has already been mentioned that there was great difficulty in applying the rock fragments, using a Michigan road scraper, so that they met the physical design criteria of Dr. Marshall's hypothesis. In the case of the second large scale field application on South Chaffer's, the initial application of railway ballast was so ineffective that a second application by hand was required over much of the

* For saltation results see Table 16.

treated area. It is likely that, in areas where the rock fragments were further apart than 3.5 times their minimum diameter, the wind velocity was not reduced sufficiently at the surface in order to restrict the saltation of sand sized particles.

5. Dr. Marshall's hypothesis requires that, to completely restrict the dust generating power of saltation, the wind force over the whole of the erodible slime dump surface would have to be reduced to a negligible amount. To do this using a discontinous array of roughness elements, Dr. Marshall calculated that the elements would have to be spaced at a maximum of 3.5 times their height apart [1].

With railway ballast of a minimum 4 centimetre diameter, and using Dr. Marshall's hypothesis, it was calculated that 40 tonnes of ballast per hectare would provide the required covering of roughness elements needed to nullify the effect of the wind force at the dump surface. The mechanical problem of spreading the material has already been mentioned and it is discussed in further detail in Section 6.2. However, besides the application of the roughness array, there is the matter of the actual shape of the elements to consider.

Dr. Marshall's initial calculations on the area of influence of each 4 centimetre element assumed the element to be a perfect sphere with a diameter (i.e. height above the dump surface) of 4 centimetres. However, railway ballast is not spherical. It is most irregular in shape and one or more of its dimensions are often much less than 4 centimetres.

To check the actual area of influence of the screened ballast used, 100 fragments taken at random from a bulk sample were dropped from a height of 30 centimetres onto a flat surface. The height of each fragment was measured and is given in Table 27.

Assuming the rock fragments had a pinnacle height and were not flat topped, the area of influence was calculated by the following equation derived from Dr. Marshall's original hypothesis [1].

$$\text{Area of Influence of fragment} = \pi . (\text{ht} \times \frac{3.25}{2})$$

Note: The distance of 3.25 times the height instead of 3.5 was used to allow an extra margin for error in the practical application of the roughness array.

The area of influence of each fragment is given in Table 27. The 100 rock fragments were then weighed and the average weight of each 4 centimetre screened fragment was calculated (0.0724 Kg). The average area of influence of each fragment was 5814 square millimetres.

Using this information it was possible to calculate the theoretical application rate for 4 centimetre screened ballast required to produce an effective roughness array. The result was a theoretical rate of 124 tonnes per hectare which is far in excess (84 tonnes or 210%) of the 40 tonne rate used on Chaffer's dump. Table 28 at the end of the report gives the details of this estimate.

Naturally such a rate would markedly increase the cost of a stone mulch treatment. At $7.80 per tonne (the 1978 purchase price) it would cost $975 per hectare for the screened ballast. This is far in excess of the $550 per hectare for the bulk treatment of Chaffer's South and this figure does not allow for pretreatment costs such as surveying, etc., or the actual machine costs for application of the ballast. A complete breakdown of estimated costs including inflation, is given in Table 28 at the end of the report.

6. It has been assumed that the roughness array treatment has been effective if the stone mulch and trapped sand combined provide a 100% cover to the surface of the slime dump.

PLATE 17 Surface of South Chaffer's on 6 August 1979 showing the almost complete layer of stone mulch and trapped sand.

As a check on the effectiveness of the rate of rock fragment application, on 1 November 1978, 100 quadrats (0.25 m^2) were thrown on the South Chaffer's treated dump. A visual estimate of the percentage cover (rock fragments plus sand blanket) was made by two independent operators and their assessments averaged. The weight of all rock fragments from within each quadrat was recorded and the results plotted against the estimated cover (see Fig. 6). The same procedure was repeated on the following day using a 1.0 m^2 quadrat and the results also plotted on Fig. 6.

Notwithstanding the apparent anomaly at 70% estimated effective cover, the results of these trials endorsed the previous theoretical calculations as to the rate of 4 centimetre ballast required to produce effective stabilization. From Fig. 6 it can be estimated that somewhere in the order of 110 tonnes per hectare of 4 centimetre screenings are required to achieve 100% cover of rock fragments and trapped sand combined.

5.4.4.2 Other Controlling Parameters

It is possible that airborne dust generation and saltation of sand are not directly related and that other parameters may be involved. In particular, it was felt that climatic conditions other than wind strength may affect the mobility of the dump material, while the physical and chemical characters of the dump material itself (e.g. soil structure, soil moisture and soil salinity) may also be involved. As samples of the dump material were not collected and analysed at the same time as the saltation and dust monitoring programmes were carried out, it is not possible to compare these latter factors at this point in time.

However, it is possible to review the effect of climatic conditions on the monitoring programmes during both the pre-treatment phase (September 1976-January 1977) and the post-treatment monitoring periods between February 1977 and January 1979 for the two treated areas on Chaffer's West and South Chaffer's.

This has been done in detail by Mr. D. Carter of the Department of Agriculture and his complete analysis is included in this report as Appendix 2. The meteorological data reviewed (rainfall, wind velocity, temperature and humidity) were supplied by the Kalgoorlie Meteorology Station which is situated at the Kalgoorlie aerodrome, some 5 kilometres west of the slime dump.

From the results of Mr. Carter's review, the following conclusions can be drawn on the effect of climatic factors on the saltation of sand across the surface of the Kalgoorlie slime dumps.

1. The saltation of sand sized particles on the slime dump surfaces increased during the summer months as the surface dried out after winter rains. Summer rainfall periods caused short-term effective reductions in the levels of saltation.

2. There was no obvious correlation between the climatic factors of wind velocity or daily temperatures and humidities, and saltation levels. While such

correlations may exist, their detection was undoubtedly restricted by the long sampling periods which made it impossible to identify the specific days during which the high levels of saltation occurred.

3. Other factors controlling wind erosion on these slime dumps would be the moisture content of the surface material, the drying rate of the surface and, to a lesser extent, the availability of erodible materials.

4. It is apparent from the results that the reduction of saltation as a consequence of a rock-mulch treatment decreased as the age of the treatment increased. This decrease in effectiveness (in terms of saltation levels only) was due to a sand blanket building up between the stones thus reducing the effective size (and therefore distribution) of the rock fragments.

5. It was felt that while the effectiveness of the stone mulch in reducing saltation decreased as this sand blanket built up the generation of further airborne dust would have still been restricted as the sand blanket would protect the dump surface from further abrasion.

   However, Mr. Riches visited the treated area at South Chaffer's on 6 August 1979. Wind conditions were quite strong (estimated at 20 - 30 knots) and even though the treated area of the dump had an almost continuous "blanket" of trapped sand (see Plate 17), large quantities of dust were seen coming from the sand covered surface (see Plate 18).

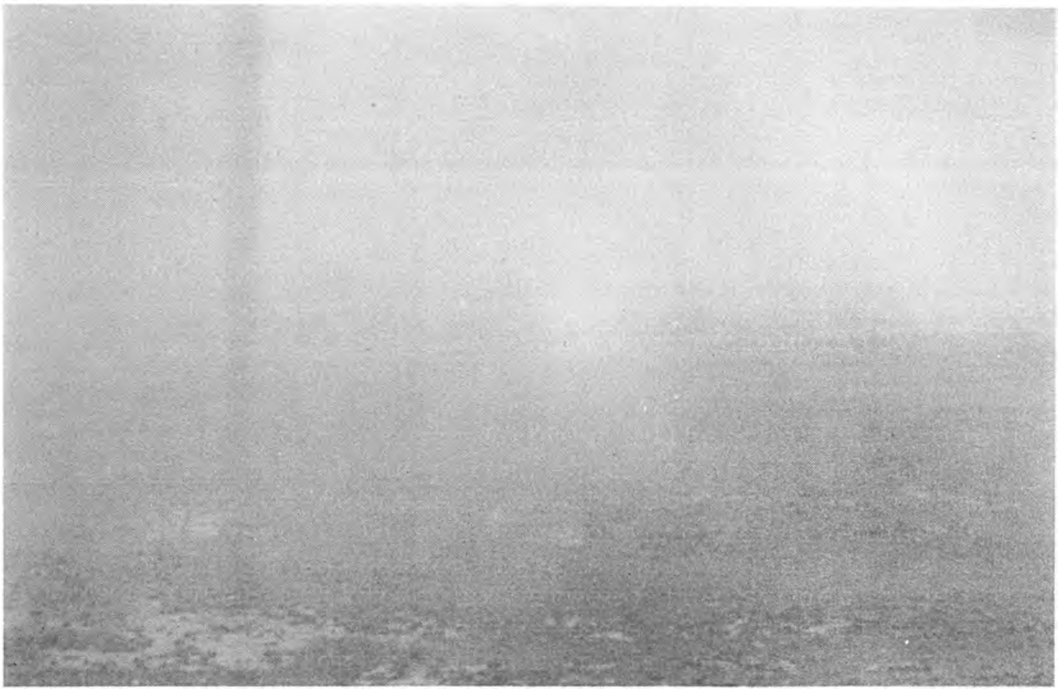


PLATE 18 Surface of South Chaffer's on 6 August 1979 showing dust generated from the stabilized surface.

Samples of the sand blanket were collected and a subsequent size analysis showed that :

20% of the sample was less than 0.150 millimetres, and

5% of the sample was less than 0.075 millimetres.

Particles of less than 0.1 millimetres will contribute to airborne dust and under moderate to strong wind conditions, the sand blanket itself can be a source of dust generation.

6. There is difficulty in mechanically applying the rock material to the dump surface on a large scale in such a manner that it meets the required physical design criteria.

7. The steep (60^{o} plus) sides of the slime dumps (up to 50 metres in height) would appear to provide a significant source of both saltating sand and airborne dust.

8. While the effectiveness of the stone mulch in reducing saltation may vary depending upon the thickness of the trapped sand and the dust entrained; the fate of the sand blanket itself in strong wind conditions is still uncertain.

5.4.5 Conclusions to Date on the Use of a Roughness Element to Stabilize the Slime Dumps

1. The application of a stone mulch to the surface of the slime dumps at Kalgoorlie reduces sand movement (saltation) across the dump surfaces. However results to date indicate that this reduction is variable and appears to decrease in time.

2. It has not been quantitatively demonstrated that a reduction in saltation causes a concomitant reduction in airborne dust generation from the waste dumps.

3. A number of factors such as the physical characteristics of the dumps themselves and climatic conditions are likely to be important parameters affecting the performance of the stone mulch treatment and therefore the suppression of airborne dust from the slime dumps.

5.4.6 Smelter Slag Trials

The research programme on the slime dumps has been designed to arrive at a practical and minimum cost, stabilization technique. Rock fragments were originally chosen as roughness elements because of the ready availability of mullock from local mines. Another material readily available at low cost is slag from the Kalgoorlie nickel smelter. This is much smaller and more uniform in size than the mullock. The slag particles are generally spherical and roughly pea-sized, and it was thought that the smaller and uniform size may have extra advantages in the case of uniform application. Some qualitative field trials were initiated to evaluate the effectiveness of nickel slag as a roughness element.

In March 1978, three areas in the Trafalgar - Penrose - Kleman's - Associated dump complex were treated with slag at the rates of 1.5, 15 and 30 tonnes per hectare. Very strong winds later in the month removed most of the slag and the trials were terminated. Treatments on 2 x 2 metre plots at 15, 30, 45, 60 and 70 tonnes per hectare also displayed instability under strong wind conditions.

In June 1979, some 652 tonnes of smelter slag were applied over 3 hectares on the Trafalgar dump. The area was graded priorto application. The cost of this treatment was roughly equivalent to the cost of applying 4 centimetre rock fragments at Dr. Marshall's theoretical rate of 40 tonnes per hectare. The object of the trials was to assess both application techniques and the stability of slag at these heavy rates. Application is still difficult to control using rubber-tyred vehicles as every bump causes a sharp change in feed rate from the back of the truck. Some removal of the slag has occurred since the application but the areas are still being observed to gauge the longer term stability at this rate in excess of 100 tonnes per hectare.

A possible disadvantage of the black smelter slag is that it may raise soil surface temperatures thus prejudicing plant survival as either a direct effect of the higher temperature, or because the increased temperature will promote more rapid drying of the soil.

Small plots were laid out on the Trafalgar dump and two different treatments were applied. Rock fragment arrays were laid out at a rate of 120 tonnes per hectare and slag treatments were applied at 100 tonnes per hectare. Untreated control plots were also established and three sets of temperature readings were taken at a soil depth of 1 centimetre in each of the plots. The results are shown on Table 29 and it is noticeable that both treatments showed significantly higher surface soil temperatures than the untreated control plots. In most cases the temperatures under the smelter slag treatment were higher than under the rock fragments.

Table 29 TEMPERATURE READINGS FROM DIFFERENT SLIME DUMP, SURFACE TREATMENTS

Date	Time	Bare Control	Slag		Rocks and Sand	
		Temp.	Temp.	% Difference from Control	Temp.	% Difference from Control
04/12/78	1030	36°C	43°C		44.5°C	
21/03/79	1018	27.8°C	30.1°C	+8%	30.0°C	+9%
	1210	33.6°C	38.0°C	+13%	35.3°C	+5%
	1407	36.5°C	40.1°C	+10%	38.0°C	+4%
	1557	35.0°C	37.2°C	+6%	34.9°C	-
23/03/79	0835	22.0°C	23.1°C	+5%	24.0°C	+9%
	1035	30.8°C	33.9°C	+10%	33.2°C	+8%
	1235	35.4°C	39.2°C	+11%	37.8°C	+7%
	1420	36.5°C	39.2°C	+7%	37.8°C	+4%
	1650	31.8°C	32.7°C	+3%	31.6°C	-

5.5 Synopsis of Slime Dump Stabilisation

1. Known chemical stabilising agents are expensive and likely to provide short term answers only.

2. Vegetative means of dump stabilization would appear to provide the best long term solution to stabilizing the disused slime dumps in the Eastern Goldfields. In the Kalgoorlie-Boulder region, the pH and salinity of most dumps (not all) is generally within the tolerable range of some of the West Australian native plants (notably the Chenopodiacaea). Elsewhere, in the Yilgarn and Murchison, either pH and/or salinity levels are likely to cause problems in plant establishment and maintenance.

   However due to the low and variable rainfall of the Kalgoorlie area, vegetative field trials are slow in producing conclusive results. Consequently there has been insufficient field testing to either clearly define or solve problems involving plant establishment on the slime dumps. Sand blasting contributes to these overall moisture/salinity problems of plant establishment.

3. At 40 tonnes per hectare of 4 centimetre, minimum diameter railway ballast, it cost in the vicinity of $550 per hectare to treat South Chaffer's dump. This

treatment then required further follow-up of material spread by hand. At the time of this report, there are in excess of 475 hectares of untreated, eroding slime dump surface (not to count the sides) in the Kalgoorlie-Boulder region alone.

4. It would appear from preliminary uncontrolled monitoring that certain factors such as climate, and the chemical and physical nature of the waste residue are intimately involved in the generation, and therefore control, of airborne dust from the slime dumps. In view of the projected costs of applying rock fragments to the surface of the dumps in the Kalgoorlie-Boulder region, and the uncertainty of its effectiveness in controlling airborne dust, it is concluded that other studies are needed before further large scale treatments can be recommended. In particular, studies are required to :

   i) develop an effective mechanical means of spreading the roughness element so that it meets the requirements of the design criteria,

   ii) test the other involved parameters (such as climatic conditions, etc.) under controlled situations,

   iii) investigate the use of alternative materials for use as roughness elements, and

   iv) assess the proportion of sand movement and dust generation from the sides of the slime dumps in relation to the total dust emission from the dumps.

5. The application of smelter slag at rates below 70 tonnes per hectare does not provide effective stabilisation as the slag blows away in strong winds. Further trials of slag at much higher application rates are warranted and such trials are currently in progress Further analysis on the effect of smelter slag and rock fragment treatments on surface soil temperatures and drying rates is also warranted in view of potential deleterious effects on plant establishment.

6. FURTHER STUDIES

6.1 Wind Tunnel Experiments

The probable involvement of other variables such as soil moisture, salinity, etc. as well as varying climatic conditions has been discussed in Section 5 and the need for further studies of these parameters under controlled situations has been highlighted in Section 5.5 of this report.

The Department of Agriculture has constructed a portable wind tunnel, designed around original plans provided by Armbrust and Box [9] in 1967. The equipment has been designed for use in the field, as well as at the Department's headquarters in South Perth.

Basically, the wind tunnel consists of a fan and driving motor mounted on a trailer. These provide an artificial airstream which is directed onto the ground surface by a rigid tunnel or duct (see Plate 19). The articial airstream can be used as an experimental tool for the research into the mechanics of wind erosion, sandblasting of agricultural crops and also the effectiveness of preventive wind erosion controls. These three areas of wind erosion research cannot be studied by means of natural wind events because of the difficulty in both variability and prediction of such events and also the inability to control them. The portable wind tunnel may not be able to perfectly simulate natural wind events, but it does allow for good controls in comparative studies of wind erosion.

PLATE 19 Portable wind tunnel.

PLATE 20 Portable wind tunnel.

6.1.1 Design Factors and Details of the Wind Tunnel

The original design of Armbrust and Box [9] considered the following factors to be important for a portable wind tunnel :

1. Wind velocities up to 65 kilometres per hour (approximately 18 metres per second) in the duct.

2. A duct length of 8 to 16 metres.

3. Tunnel rotation from 0 to 90 degrees.

4. A duct tall enough to be placed on sorghum stubble.

5. Flow patterns comparable to natural winds.

All of these factors except 3 and 4 have been considered in the design of the wind tunnel for the Department of Agriculture and other considerable additons have been made. These are :

1. A "tent" shaped duct so that the air volume flow is maintained as in the original design but that a greater ground surface area is covered.

2. It has the capacity for pulsating air velocities to simulate air turbulances, as well as the capacity for recycling the collected saltating materials so as to simulate a plot of infinite length.

A 1,200 millimetre Euclid fan (belt driven, axial flow, aerofoil fan) capable of delivering 28,300 litres per second against 450 PA is driven by means of a 4 cylinder Ford diesel engine. The maximum input power to the fan is 40 kilowatts. The motor and fan are mounted on a low loader trailer along with the lifting crane and other accessories (see Plate 20). The tunnel ducting is attached to the fan by means of a transition tunnel which is pivoted to allow for the raising and lowering of the tunnel without resorting to unhitching the tunnel from the fan. This enables the tunnel to be lifted by the crane when the trailer is moved from plot to plot.

In between the transition tunnel and the fan, a set of rotating louvres driven by a separate electric motor will constantly change the wind velocity in the tunnel. The variations (in wind velocity) have a frequency of change in the order of 1 - 3 Herz. This is thought to simulate the medium sized eddies which are apparent at ground level in natural wind events. The magnitude of the variability in wind speed is ± 30% of the mean velocity, again another assumption of the natural wind.

The duct is constructed in three interlocking sections each 2.370 metres in length. The duct has a cross-sectional area of 1.2 square metres and at 28,300 litres per second maximum fan output this represents a velocity of approximately 28 metres per second (i.e. 100 kilometres per hour). The maximum area of contact with the ground is 10.7 square metres and the height of the tunnel is 0.95 of a metre.

The transition tunnel is designed to take the air from the fan down to the ground level and with the straighteners in place, direct the air parallel to the ground surface. Immediately behind the straighteners, the saltation material, which is collected at the open end of the tunnel, is reintroduced into the air stream. This is done because in a natural wind event, any specific plot is influenced both by that which is blown from the plot as well as that which is blown onto the plot. By this manner a test plot of infinite length can be created and tested.

6.1.2 Details of the Wind Tunnel Studies

The wind tunnel has been used to measure the quantity of suspended (dust) and saltated (sand-sized) materials generated in a standard wind event produced by the wind tunnel; and to determine the correlation between surface saltation and dust levels under various conditions of soil moisture and surface chloride (salinity) levels at the Kalgoorlie and Bullfinch (see later) slime dumps.

Direct extrapolation of these results to natural wind events may be unwise, but if controlled comparative conditions are available in the research program, treatment effects will certainly be tested with some degree of confidence. Although the wind tunnel has been commissioned and partially evaluated, the comparison of natural and artificial wind events cannot really be commented on, other than by speculation.

The study looked in detail, under a variety of controlled variables, at the ability of a stone roughness array to prevent the generation of dust from the surface of slime dump material. To facilitate further control and calibration, it is proposed to set up an artificial bed of slime dump material at South Perth. This will enable more frequent monitoring and better moisture control of the dump material than would be possible in the field situation.

If time permits it is also hoped to obtain basic physical information about the slime dump material and how its surface morphology changes with salinity, and wetting and drying cycles. After several field trial have been conducted on the slime dumps at Kalgoorlie it is proposed to perform further testing at South Perth, requiring 30 tonnes of slime dump materials to be brought to Perth.

Mr Carter of the Department of Agriculture has provided a detailed description of the proposed trials to be conducted at South Perth, listing the variables to be tested and the number of different roughness element treatments proposed in Appendix 3.

During 1980 two experimental areas were set up on Klemans dump to test the effectiveness of both smelter slag and rock fragments. These experiments were also designed to determine the dustiness of the sand blanket which builds up on the treatments after they have been laid down. The presence of a sand blanket was not anticipated on the original Marshall rock meadow treatment, so its role in dust generation was not known. Both of these experiments were hampered by rain and the expanded experiment in December 1980, by mechanical breakdowns. This led to an incomplete replication of the treatments, however the results obtained were quite clear.

The results of the experiments conducted in April, and December 1980 are given in Tables 31 and 32. The April experiment was virtually a pilot study but indicated that the sand blanket was important (as expressed in Section 5.4.4.2). The December 1980 experiments were conducted on a surface which was found to be very stable to wind erosion even at the highest speeds. The only treatments which showed significant saltation and dust were those which had been laid down some three months earlier in order to accumulate a sand blanket between the rocks and smelter slag.

The other important revelation was that the accumulated sand was less on the lowest rate of rock application therefore resulting in less saltation. This is discussed below.

The smelter slag and rocks treatments which were put down immediately prior to wind tunnel testing, to avoid a sand blanket covering, showed very little saltation because of the stable surface. The rock application registered a slightly higher reading simply because of the disturbance of the dump surface due to the application methods. However, this was insignificant compared to the rocks which had a sand cover.

The smelter slag decreased both saltation and dust levels considerably when compared to the rocks and sand covering treatment. The amount of dust arising from the smelter slag was still noticable in the wind tunnel test but in terms of an atmospheric nuisance the amounts were low, especially in the higher velocity winds. This latter fact could be caused by the removal of dust in the lower wind speed runs, therefore indicating a small reservoir of saltation and dust collecting on the smelter slag. The reservoir on the rocks was much greater because of the depth available to be filled by incoming saltation materials.

This experiment did little to test the Marshall rock meadow theory because of the complications of the sand blanket and the untreated areas did not blow at all. Therefore further testing was carried out on the very dusty surface of the GMK No 2 dump in March 1981. The results were conclusive that depending on the wind speed the rock treatments were able to significantly reduce the amounts of dust and saltation coming off the dump surface, as shown in Tables 33 and 34. It appeared that the most effective application rate was somewhere between 80 and 160 tonnes per hectare.

This experiment did prove the effectiveness of the rock application method on a highly erosive surface with no sand blanket. The Marshall rock meadow theory, however, breaks down in practice if the exposed dump surface between individual rocks is filled up with sand coming from outside of the area. This was clearly shown in the partially completed experiment on Klemans dump, where the sand blanket which built up on the rock meadow treatment contributed significantly to the dust load in the air. The Klemans experiment also showed that the dust and saltation levels were greatly reduced if smelter slag was used to cover the dump surface even if outside sand sources were causing accumulation.

In Section 5.5.5 it was mentioned that smelter slag had the disadvantage in that it tended to blow away at rates of less than 70 tonnes per hectare. In the Klemans experiment the rates were 100 to 300 tonnes and there was no evidence of stripping of the smelter slag even at high wind speeds. The stability of the smelter slag is, however very dependent on the smoothness of the dump surface where any irregularity might allow the dump surface to be exposed through the smelter slag cover. Another advantage of smelter slag is that it provides a surface mulch effect for seed and plants which would hold the young seedlings in place during the early establishment period. The seeds could easily be spread immediately prior to the smelter slag application.

6.2 Application of the Roughness Elements

The implications of the actual shape of the individual elements of the roughness array, and the rate and uniformity at which it is spread has already been discussed in considerable detail in Section 5.4.4.1. Notwithstanding these problems, there is still the difficulty of finding an effective means of mechanically spreading the stone mulch so that it meets the design specifications.

The current GDAC Ranger, Mr. Joe Houldsworth has come up with a proposed design based on a modified sand-spreader attached to the back of a standard 12 cubic metre tip truck. Mr. Holdsworth has presented his plans to the engineering firm of Vickers-Keogh in Kalgoorlie which is currently developing a proto-type. It is anticipated that the unit should be completed by November 1980 and will therefore be available for field testing during the 1980-81 summer period.

6.3 Bullfinch Slime Dump Stabilisation

6.3.1 Background

The town of Bullfinch is located 30 kilometres north north-west of the township of Southern Cross and 440 kilometres from Perth. The town, which normally services a farming community of approximately 80 people, has been increased slightly in recent times by the arrival of a number of prospectors and mining company personnel actively engaged in gold exploration.

In its hey-day when the Great Western open cut and the Copperhead shaft were operating (1953-1964), there were over 1500 people resident in Bullfinch. This gold mine was operated by Great Western Consolidated which was a subsidiary of Western Mining Corporation. During the 10 years that the company operated, a total of 4.7 million tons of ore were treated for a return of 685,486 ounces of gold.

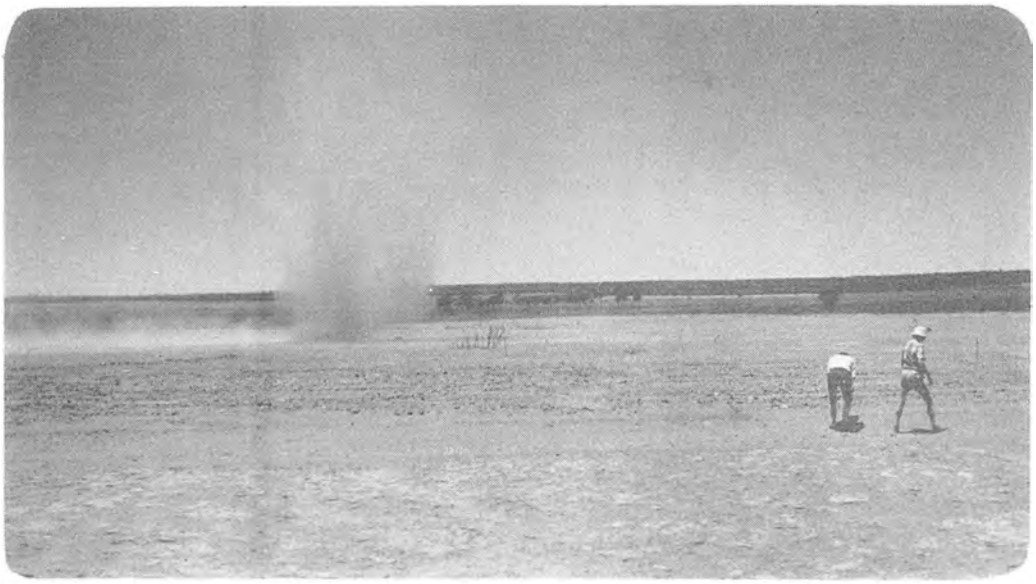


PLATE 21 The Copperhead slime dump at Bullfinch, W.A.

The waste residue from the treatment of the ore was dumped one and a half kilometres immediately north-east of the townsite on C Class reserve 23972 (see Plate 21). This reserve is for "mining purposes". It was gazetted in July 1954 and it is still vested in the Minister for Mines. The dump, which has recently been the subject of a number of mining tenement applications, is approximately 40 hectares in area. Mullock from the open-pit operations has been dumped immediately adjacent to the east and south margins of the slime dump (see Plate 22).

Because of the proximity of the dump to the townsite and its up-wind location with respect to the prevailing summer easterly winds, the slime-dump has been a continuing source of nuisance dust to residents of Bullfinch since the mid sixties (see Plate 23).

PLATE 22 The Great Western open cut and adjacent mullock dumps.

PLATE 23 Dust lift-off from the Copperhead slime dump at Bullfinch.

The Bullfinch Progress Association first brought the matter of dust from the dump to the Government's attention in February of 1976 when it wrote to the Mines Department requesting permission to use the dump as a rubbish disposal site. The Association hoped that the rubbish would promote stabilisation of the slimes surface and so reduce dust. Permission was refused by the Mines Department although in consideration of the problem it referred the Association to the Department of Agriculture and at the same time suggested possible methods of alleviating dust using either vegetative means or the spreading of gravel.

The Bullfinch Progress Association approached the Department of Agriculture which offered advice and in winter of 1977 carried out some plant trials on the dump using native species. At the same time, the Department of Agriculture referred the Association to the Department of Conservation and Environment for possible funding assistance. This Department investigated the matter. Inspections were carried out and correspondence with both the Departments of Lands and Surveys, and Mines, determined the ownership and tenure of the land and mining tenements involved.

Approval was sought from, and given by the Under Secretary for Mines (on 15 September, 1977) for Conservation and Environment to arrange for rehabilitative work to be carried out similar to that being undertaken at Kalgoorlie. Early reports of the GDAC work using a stone mulch treatment on the Kalgoorlie dumps laid claim to 70-90% effectiveness in the reduction of saltation and dust. Because of the cost factors, the small population of Bullfinch and its considerable distance from any active rock quarry, it was not possible to apply 4 centimetre railway ballast to the Copperhead slime-dump. However Dr. Marshall's hypothesis emphasised the spacing of the roughness elements as the critical factor; not their actual size.

Because of the readily available mullock around the Copperhead slime-dump, and the willingness of the Bullfinch residents to actively participate in the resolution of their dust problem, it was agreed that trials would be carried out on the slime dump prior to the application of a variety of cheap treatments using a range of readily available local materials as alternative roughness elements.

It was seen that the Bullfinch situation had a number of features which would favour its effective monitoring and therefore the assessment of the success of the treatments.

6.3.2 Advantages of the Bullfinch Study Site

1. The most important factor in favour of carrying out monitoring at Bullfinch is that there is only the one slime dump present and therefore a single source of dust. At Kalgoorlie there are many dumps in close proximity and dust from adjacent untreated dumps could be interfering with results from the gauges on the treated portions of Chaffer's. As a one dump-one treatment situation, Bullfinch could provide some very valuable comparative data which could assist in the interpretation of the Kalgoorlie work.

2. The population of the Bullfinch area is low and most children (there are about 35) above the primary school age are at boarding school. The risk of vandalism to the sampling equipment is low compared to Kalgoorlie-Boulder.

3. The project has the full support of the Bullfinch Progress Association and the people of Bullfinch are prepared to assist (labour and vehicles) on a voluntary basis in the treatment of the slime dump.

4. As has already been stated there is an abundant supply of mine mullock immediately adjacent to the slime dump which could be used for the stone array. This is freely available at no cost other than cartage and application. The 4 centimetre railway ballast used at Kalgoorlie costs $7.80 per tonne to purchase.

   As an alternative source of stone mulch there is the abandoned Bullfinch-Mukinbudin railway line immediately north of the township. The rails have long since been removed, but the base of sized ballast still remains. This could be used to provide a sized stone mulch if required.

6.3.3 Work to Date

6.3.3.1 Wind Strength Monitoring

Since August of 1978, a Lambrecht Woefle, continuous anemometer has been monitoring wind speed and direction on site. The recorder is situated on a 3 metre pole which is located in the centre of the cleared paddock immediately east of the slime-dump (see Plate 24). The anemometer measures wind speed and direction which is recorded on a continuous chart. The anemometer was serviced every 28 days. These charts are digitised by the Bureau of Meteorology and results are given as average wind speed in metres per second for every one hour period. Wind direction is given as 10^{o} sectors for every half hour period. The complete record of digitised results is available from the Department of Conservation and the Environment.

PLATE 24 Maintenance of the Woefle anemometer sited east of the Copperhead slime dumps (in background).

6.3.3.2 Base Monitoring of the Dump Surface

At the same time that the anemometer was sited, 100 uni-directional saltation gauges were installed on the Copperhead slime dump. The gauges were laid out in two replicates of 50 gauges; one towards the lower and eastern edge of the dump and the other towards the western and higher portion of the dump. The gauges were all aligned on a direct bearing from the centre of the dump to the centre of the town and presumably the one therefore which parallels the direction of the wind creating the major dust problem. Each bank of 50 gauges has been laid out in 5 sets of 10, each with 5 gauges situated exactly 50 metres directly upwind (i.e. 050^{o}) of the other 5 gauges (see Fig. 7).

A further 10 saltation gauges have been sited at the base of the anemometer in the paddock immediately east of the slime dump. Their purpose is to provide basic information on saltation levels across these paddocks in dry seasons after a poor harvest, or during summer periods when this paddock has been left in a fallow state.

The objectives of the base saltation monitoring has been to :

- i) determine summer levels of saltation from the Copperhead dump, and
- ii) detect variability, if any, in the erodibility of the dump surface.

Saltation samples have only been collected during the summer months and even then, particularly during the 1978-79 summer, some of the samples have had to be discarded because of contamination by surface run-off. This is a particular problem at the Copperhead dump because of the manner in which the dump was originally constructed. Tailings were released from a pipehead at the top of a hill and were allowed to run down the hillside until collected by a bund at the bottom of the hill to the east of the mine. This means that the surface of the dump is not level as is the norm in the Kalgoorlie-Boulder dumps which have been constructed on level ground. Consequently under rainy conditions surface run-off containing dump material was collected in the saltation gauges thus contaminating the results. All samples have been oven-dried and those containing excess water have not been included in the results.

In general, saltation samples were collected on a fortnightly basis as this seemed to be about the time required for the gauges to become almost full. However on odd occasions; when either strong east or north-easterly winds blew, or moderate winds from the same direction blew for prolonged periods; the gauges had to be serviced more frequently (sometimes less than one week). In all instances however saltation samples were collected on the same day that the anemometer and CERL gauges (see next section) were serviced so that all results were directly comparable on the same time base.

The complete record of saltation results is available from the Department of Conservation and Environment.

6.3.3.3 Airborne Dust Monitoring

On 28 October 1978, a total of 10 CERL dust gauges were installed at Bullfinch in the locations shown on Plan 2. A further two gauges were installed on the slime dump on 23 March 1979. These have been sampled every 28 days by officers of the Merredin Office, Department of Agriculture at the same time as the saltation gauges and the Woefle anemometer have been serviced. The samples are collected from each CERL pot, placed into jars of distilled water and sent to Perth for analysis by the Clean Air Section of the Department of Health and Medical Services. Results are presented in full as milligrams of dust weight, and units of obscuration and total dirtiness in Appendix 4.

The results of the dust sampling were then sent to the Department of Agriculture for computer analysis and comparison with the results of the saltation monitoring programme.

6.3.4 Results

6.3.4.1 Saltation

The Copperhead slime dump at Bullfinch is far more mobile in terms of saltation than any of the dumps monitored to date in the Kalgoorlie-Boulder region. This is evidenced by as much as 2710 grams of saltated sand having been collected in a single gauge at Bullfinch within a 6 day period (see results for 7 November 1979). In fact this is not a true measure of the maximum saltation as on several occasions some samples had to be discarded because some of the gauges were overflowing.

The maximum saltation samples recorded from Kalgoorlie were up to 747 grams collected in an 8 day period at the end of February 1977. It is noteworthy that this was a particularly dry and windy period. Saltation figures are generally much lower than this maximum for the Kalgoorlie dumps.

6.3.4.2 Airborne Dust

Dust levels measured from those gauges sited within the Bullfinch townsite (see Plan 2) are similar to levels recorded from the Perth metropolitan area and the Kalgoorlie and Boulder residential areas. Considering that the monitoring period from October 1978 - February 1980 covered the end of a serious drought in the district, these dust levels do not indicate that there is a serious dust problem in the main Bullfinch townsite.

However, the two gauges situated near Mr. Ken Taylor's farmhouse south of the slime dump (No. 9) and the group of ex-mine management houses immediately north-west of the old Copperhead shaft (No. 7) show dust levels higher than those experienced in the townsite itself. These results reflect the closer proximity of these gauges to the dump.

The CERL gauge (No. 10) sited in Mr. Taylor's paddock immediately east of the dump showed very high dust levels on occasions corresponding to periods of farming activity in the paddock, or periods of high westerly wind erosion from the dump.

Measurements from CERL gauges installed on, and immediately adjacent to the dump, recorded extra ordinary dust levels encountered elsewhere only on the slime dumps at Kalgoorlie. Because the results from these gauges (No. 1, 2, 3, 11 and 12) are so much larger and out of proportion to the rest of the results, they have not been graphically presented although the actual measurements can be found in Appendix 4. However, for the purposes of comparison with Kalgoorlie, a graphical presentation of the results from the other seven CERL gauges at Bullfinch is given in Figure 8. Results have been plotted in units of total dirtiness.

6.3.4.3 The Relationship Between Saltation and Airborne Dust

As previously mentioned all saltation and dust results were sent to the Department of Agriculture for computer and regression analyses of the relationship between saltation and dust generation. Review of monitoring carried out during the 1978-79 summer period enabled the following conclusions to be drawn.

1. Saltation is not uniform over the whole dump surface. It is influenced by surface soil conditions; in particular salinity, soil moisture and crusting of the top layer of material. Furthermore, the surface saltation is a dynamic situation which changes as the soil surface dries out, crusts form and then decay. This is illustrated in the following table .

Table 30 Analysis of Bullfinch Saltation Results - 1978-79.

Date	4 Jan - 15 Jan, 1979				Std Error	Coeff. var.
Row No.	1	2	3	4		
Mean Saltation per gauge (gms)	1456	1483	1485	1446	159.4	10.9
Date *	13 Mar - 23 Mar, 1979					
Row No.	1	2	3	4		
Mean Saltation per gauge (gms)	28	52	1245	1134	89.7	14.6

* This sampling period was after rain.

In the period 4 - 15 January, saltation was occuring uniformly over the dump surface. However, the second period after rain in March shows a marked variation in saltation levels between the gauges. It is thought that this variation in saltation over the trial area was due to differential crusting effects of the dump surface caused by the effect of rainfall.

2. Secondly, results showed that saltation increases with time through the summer months, although it is temporarily reduced by individual summer rainfall events. With the onset of frequent autumn rains, saltation levels are markedly reduced.

3. Regression analysis of the 1978-79 saltation results and the dust results from the three CERL gauges sited on the slime dumps gave correlation coefficients for each of the dust gauges of 0.88, 0.78 and 0.81. The variance accounted for was only of the order of 50% thus indicating that other variables are involved. The original hypothesis, on which the stone mulch treatment was based, that dust generation was only correlated with saltation has been found to be incorrect. There are many more factors involved, some of which include soil moisture, salinity, the effect of surface crusting and the availability of loose material.

The 1978-79 monitoring was repeated during the 1979-80 summer season and these new data were analysed in the same manner. Results confirmed the above conclusions that the unknown variables involved could not be measured with the resources which were available and on the time base which was used. More effort and resources, including monitoring on a much smaller time base with the recording of peak wind events, would have to be committed to the project in order to be able to define and interpret the interrelationship of the variables involved.

However, it is believed that Bullfinch, with its backlog of already recorded base data and the fact that it provides a single point source of dust generation in comparison to the multitude of dumps at Kalgoorlie; remains an ideal experimental site for the monitoring of dust generation from abandoned mining waste dumps.

A complete record of the computer analysis of results is kept at the Department of Agriculture at South Perth and is available on request.

6.3.5 Bullfinch Vegetation Trials

Early in 1977 vegetation trial sites were selected on the southern portion of the Copperhead slime dump. Prior to the break of the winter rains, contours at 3 metre vertical intervals were put in using the local authority's road grader.

Soil samples of the trial sites were taken and the analytical results are given below :

Salinity	1.5 - 2.5% TSS
pH (surface)	3.5 - 4.5
pH (sub-surface)	3.5 - 6.8

After the onset of winter, standard plant establishment trials were carried out on the contour banks using a Mallen seeder. Plants chosen for the trials were all natives to the area which are adapted to harsh and relatively saline conditons (i.e. Arthrocnemum spp, Atriplex nummularia and A. stipitata).

Results were most disappointing and no germination was recorded. At the time it was thought that the below average rainfall for 1977 may have been a major factor contributing to the failure of germination.

In 1978 after the break of the winter rains, a similar experiment was implemented to determine the combined effect of fertilizer and surface roughness on the establishment and survival of various members of the Chenopodiaceae on the Copperhead slime dump.

Six species were planted along contour lines again using the Mallen seeder. Fertilizer (200 kilograms per hectare of No. 1 mix superphosphate plus 200 kilograms of plain superphosphate) was also applied at seeding. The ground between the contour banks was chisel ploughed at the time of seeding in an attempt to provide a short-term, roughness array which would reduce saltation and therefore the effect of sand-blast on any young seedlings.

Some of the seed germinated but all failed to survive the ensuing summer. It is thought that the lack of available moisture and the effect of strong sand blast were the two major factors causing the failure of the plants to survive. The species which germinated were Atriplex nummularia, A. stipitata, A. bunburyana, A. vesicaria and Maireana brevifolia (see Plate 25).

PLATE 25 Atriplex seedlings germinated on a contour line on the Copperhead slime dump at Bullfinch.

7. CONCLUSIONS

7.1 Kalgoorlie-Boulder Slime Dump Stabilisation

1. The application of a stone mulch roughness array to the surface of the slime dumps can be shown to reduce sand movement by saltation. This has been conclusively demonstrated by the GDAC following Dr. Marshall's work [1]. However the extent to which the roughness array reduces saltation appears to be rather variable and is dependent on a number of factors. These include the relationship between the height of the roughness elements and their distance apart, the depth and extent of the trapped sand blanket, the availability of nearby unstabilised sand (e.g. from the sides of the dumps) and the effectiveness of physically spreading the stone fragments.

2. In hindsight and from the monitoring to date, it cannot be shown quantitatively that the use of a roughness array in the form of a stone mulch has reduced airborne dust coming from the slime dumps at Kalgoorlie. At this point it would appear that other variables, essentially sand on the talus slopes, and possibly soil moisture, soil salinity, rainfall etc, are involved.

7.2 Bullfinch Slime Dump Stabilisation

1. The slime dump stabilisation work at Bullfinch evolved from the work already being carried out by the GDAC at Kalgoorlie.

2. Bullfinch provides an appropriate location for further trials using a stone mulch treatment because it provides a single source, and therefore one dump - one treatment situation which is not available in Kalgoorlie (see section 6.3.2).

8. RECOMMENDATIONS

8.1 Coordinated Research and Funding

1. The long-term stabilisation of mining waste residue dumps in the arid West Australian environment is essential if reasonable standards of environmental quality control are to be established and maintained in such important regional centres as Kalgoorlie-Boulder. However the problem of dust from slime dumps is not restricted to Kalgoorlie and Boulder alone. There are a large number of much smaller population centres in Western Australia which owe their start to bygone mining activities and which also have a present day dust problem directly attributable to mining.

   In some cases, particularly Kalgoorlie, the soil conditions of the slime dumps (salinity and pH) fall within the tolerable range of some of the native plant species such as the Chenopodiaceae. In other cases where the ore contained sulphides and/or where saline groundwaters were used in the concentrating processes, the slime dumps are presently unfavourable sites for plant establishment because of acidity and/or salinity respectively. In either case because of the extreme shortage of freshwater and the very low annual rainfall, tried and accepted methods of vegetative stabilisation (including the leaching of salts) are simply not possible.

2. Original research is required and because of the size of the areas involved and anticipated costs of treatment, all such research in the State should be coordinated to maximise the chances of success and to minimise the costs to both the tax-payer and the mining industry.

3. Government support (staff and budgetary) should be continued for the next five years in order that the slime dump stabilisation work can be continued. There is little point in having introduced other dust abatement measures in Kalgoorlie-Boulder without stabilising the slime dumps.

4. Community involvement is seen as an essential component of successful dust abatement and to maintain and further this, as well as to continue with the essential tree planting and regeneration work in and around the Kalgoorlie-Boulder region, it is strongly recommended that the GDAC should continue to operate and receive State Government financial support.

5. In order that the slime dump research be effectively coordinated, a technical sub-committee to the GDAC has been formed and the State Departments of Agriculture, Forests, Public Health and Conservation and Environment are currently represented. The CSIRO Division of Land Resources Management is also represented.

   Most of the technical expertise required is available within the range of existing State Government departments and a suggested organisation for effective research coordination is given as Fig. 9. This framework should however be quite flexible so that specific expertise can be added (or subtracted) to the technical advisory committee as required.

   For example, it is suggested that a Mines Department representative should be added to the technical sub-committee in order to :

   (i) advise the GDAC, through its sub-committee, of new mining tenement applications in the regeneration zones; and

   (ii) advise on the mining engineering aspects of tailings dam design so that the rehabilitative aspects are compatible with the objectives and engineering design criteria.

It is also recommended that the Department of Conservation and Environment continue to provide the secretariat required for research coordination. As is the current situation, a special State Treasury allocation should be made for funding the research and these monies should be made available to the GDAC through the Department of Conservation and the Environment.

6. Furthermore, through the GDAC Technical Sub-committee, there should be a thorough legal examination of the penalties for trespass and the authority for control of the various classes of land within the regeneration zones. Proper legal advice is required to sort out the complexity resulting from the existing variety of tenure under the Land Act, the Mining Act and the Local Government Act. This advice could take place through the Technical Sub-committee with input from, for example, the Crown Law Department.

8.2 Immediate Applied Research

1. The wind tunnel experiments indicated that sand from the surface of the slime dump, or from an outside source such as the talus slopes, negates the effect of the rock meadow treatment. Further tests should be carried out to determine the source of the sand blanket, with the wind tunnel if applicable. Funds for extra costs should be made available through Department of Conservation and Environment.

2. Work should proceed to develop a cheap method of stabilising or binding the sand on the talus slopes to prevent it from blowing across the dumps and/or forming a sand blanket on a rock meadow treatment.

3. Further small scale studies are required to investigate the availability, application and performance of other materials which could be used as a cheaper type of roughness array. The GDAC has carried out some preliminary work using slag from Western Mining Corporation's smelter at Kalgoorlie. At the theoretical rates as recommended by Dr. Marshall's hypothesis, smelter slag has been found to be unstable under heavy wind conditions. However further trials at much heavier rates of application are continuing. Smelter slag and any other possible alternative materials should be tested for performance in the wind tunnel prior to any large scale field application.

4. Some of the vegetative work carried out by the Department of Agriculture on the Associated dump at Kalgoorlie has yielded interesting results with some of the plants, principally *Atriplex stipitata* and *Maireana brevifolia*, flourishing and into their third year. Monitoring of this site should be continued in order to observe the growth and development of these species in slime dump material in a field situation. However further field trials are required to determine the most likely species to survive once saltation has been controlled, and the various types and application rates of fertilizer required to promote growth and maximise the chances of survival.

8.3 Continued Monitoring

1. It is recommended that the CERL dust monitoring currently being carried out by the Department of Health and Medical Services in the Kalgoorlie-Boulder region be continued. Not only will this provide invaluable background information against which to assess the effectiveness of dust abatement measures as they are introduced, but it will also provide useful information for comparing the "total dirtiness" of Kalgoorlie to other parts of the State.

2. The CERL dust and saltation monitoring of the untreated Copperhead slime dump at Bullfinch should be continued (in summer months only) to provide the essential basic data against which to compare the results of future stabilisation treatments, should they be applied. Application of these treatments should be dependent on the results of the trials using the wind tunnel (see Section 6.1.2).

3. Slag trials already initiated at Kalgoorlie should continue to be monitored to assess the effectiveness of this alternative treatment.

8.4 Further Stone Mulch Treatments

1. No further large-scale application of stone mulch is recommended at this point in time. The Marshall rock meadow treatment of dumps should only be contemplated if the outside sand source is stabilised or does not exist..

2. The smelter slag option should be further investigated on larger scale pilot areas to assess its ability to remain in place and its effect on seedlings and plant growth.

3. Because of the large areas involved and the present flurry of gold exploration and mining activity with retreatment of many slime dumps, caution is urged before any further large scale treatments are considered.

8.5 Future Prevention

It is obvious that past design criteria for slime dumps have not taken into consideration the dust problem which eventuates once the dumps dry out. Consideration should be given now to the future prevention of this problem which occurs once mining activities cease and which continues long after the mine is decommissioned and the tenements relinquished.

Perhaps appropriate conditions of approval for present and future mining tenements involved could be formulated. Such conditions might require the holder of the tenement to stabili e the dump surfaces prior to the cessation of mining and treatment operations, or the relinquishment of any tailings leases.

It is recommended that this report provide the basis for a Cabinet endorsed request for the matter to be reviewed by the Minister for Mines and his Department.

9. ACKNOWLEDGEMENTS

Thanks are due to all the members of the GDAC for their continued support and to the following technical personnel for their enthusiastic involvement in the monitoring and assessment programmes :

Mrs. Alison Curnow	-	Department of Agriculture - Kalgoorlie
Mr. Jim Addison	-	Department of Agriculture - Kalgoorlie
Mr. John Law	-	Department of Agriculture - Kalgoorlie
Mr. Ian Pettingill	-	Department of Agriculture - Merredin
Mr. John Feldman	-	Department of Agriculture Merredin
Mr. Joe Houldsworth	-	GDAC Ranger
Mr. Michael Maher	-	Department of Conservation and Environment
Mr. Graham Smith	-	Department of Health and Medical Services
Mr. David Briegel	-	CSIRO - Division of Land Resources Management
Mr. Norm Caporn	-	Forests Department, Kalgoorlie.

Special thanks are also due to Mrs. A. Ried (Secretary of the Bullfinch Progress Association) and Mr. Ken Taylor of Bullfinch for their contributions in the Bullfinch monitoring programmes.

10. REFERENCES

1. Marshall, J.K., Morrissey, J.G. and Richmond, P.C. Control of dust from slime dumps at Kalgoorlie. Proceedings of a meeting held in Perth on 11 October, 1978. Rehabilitation of Mined Lands in Western Australia, Western Australian Institute of Technology.

2. Richmond, P., Hacker, R. and Verschuer, J. (1973). Report on the dust problem in the Kalgoorlie-Boulder region. Prepared for the Honourable Minister for Environmental Protection, Perth, Western Australia. 37 pp. Department of Conservation and Environment.

3. Goldfields Dust Abatement Committee (1978), Progress Report to June 1978. 10 pp.

4. Goldfields Dust Abatement Committee (1979), Progress Report to December 1979. 40 pp.

5. Lamont, B.B. (1976). The Soils and Plants of the Eastern Goldfields with Particular Reference to the Capacity of the Tailings Dumps to Support Vegetation. WAIT-AID Ltd. ref. 7404059.

6. Marshall, J.K. (1971). Drag measurements in roughness arrays of varying density and distribution. Agr. Meteorol. 8, 269-292.

7. Marshall, J.K. (1972). Principles of soil erosion and its prevention. In 'The use of trees and shrubs in the dry country of Australia', (Ed. N. Hall). (Australian Government Publishing Service: Canberra).

8. Marshall, J.K. (1974). Effects of stock on micro-environments in Australian rangelands. U.S.D.A. Misc. Publ. 1271, 167-185.

9. Armbrust, D.V. and Box (Jr.), J.E. (1967), Design and operation of a portable soil-blowing wind tunnel. U.S.D.A. ARS, 41-131, March 1967, 14 pp.

10. Skidmore E.L. (1965). Assessing wind erosion forces: Directions and relative magnitudes. Soil Sci. Soc. Am. Proc., 29, 587-590.

APPENDIX 1

COMPLETE RECORDS OF THE
EAST/WEST SALTATION RESULTS
FROM CHAFFERS WEST DUMP.

APPENDIX 1

Complete Records of Saltation Results from Chaffer's East and West Dumps.

NOTE:
1. Figures are grams weight of soil collected.
2. There are four rows of gauges (1-4) with three gauges (a-c) in each row.

Period of Collection		EAST				WEST			
		a	b	c	$\bar{x}$	a	b	c	$\bar{x}$
27.9.76 to 8.10.76	1	9.3	6.8	2.7	6.3	74.2	46.4	42.6	54.4
	2	6.8	2.6	2.5	4.0	88.3	37.9	25.5	50.6
	3	8.4	7.9	6.6	7.6	46.5	64.5	46.6	52.5
	4	5.7	3.8	14.6	8.0	44.0	11.8	170.1	73.3
8.10.76 to 14.11.76	1	26.2	19.0	17.4	20.9	70.2	21.9	19.6	37.2
	2	30.9	52.2	24.3	35.8	19.0	56.9	13.3	29.7
	3	35.0	24.7	35.2	31.6	12.4	10.6	11.1	11.4
	4	21.6	33.9	13.8	23.1	101.3	50.7	110.8	87.6
14.11.76 to 27.11.76	1	31.0	27.6	35.8	31.5	18.5	19.5	17.4	18.5
	2	37.5	29.0	37.3	34.6	14.9	20.0	13.8	16.2
	3	46.9	39.2	61.2	49.1	22.2	12.7	11.6	15.5
	4	35.6	49.2	47.4	44.1	25.9	14.5	31.2	23.9
27.11.76 to 19.12.76	1	45.1	59.1	47.6	50.6	51.3	50.7	69.8	57.3
	2	30.0	29.9	37.3	32.4	44.5	104.9	33.7	61.0
	3	46.7	17.7	34.8	33.1	21.5	26.3	28.4	25.4
	4	15.2	26.0	25.6	22.3	96.7	32.2	120.9	83.3
19.12.76 to 8.1.77	1	312	340	292	314.7	394	447	467	436.0
	2	323	340	347	336.7	402	649	425	492.0
	3	391	388	398	392.3	461	370	497	442.7
	4	294	359	479	377.3	585	544	820	649.7
*5.2.77 to 16.2.77 *Estimated start date	1	673	776	534	661	379	411	477	422
	2	604	586	549	580	450	496	388	428
	3	541	505	648	565	48	37	41	42
	4	355	443	520	439	39	42	45	42
16.2.77 to 22.2.77	1	229	226	169	208	256	301	326	294
	2	243	241	210	231	282	333	276	297
	3	252	195	226	224	61	63	60	61
	4	319	319	311	316	32	31	34	32
22.2.77 to 25.2.77	1	514	531	401	482	499	548	567	538
	2	522	583	542	549	475	521	401	466
	3	517	454	622	513	174	168	157	166
	4	500	546	589	545	110	96	101	102
25.2.77 to 5.3.77	1	656	742	559	652	538	606	747	630
	2	627	636	599	621	513	606	424	514
	3	618	513	717	616	156	158	162	159
	4	482	650	696	643	107	111	113	110
15.9.77 to 26.9.77	1	9.8	7.9	13.3	10	8.1	8.3	7.6	8
	2	13.9	10.9	12.3	12	5.9	8.2	6.9	7
	3	12.6	12.0	12.5	12	3.5	6.6	4.6	5
	4	9.1	10.7	13.6	11	2.0	2.3	3.8	3
15.11.77 to 11.12.77	1	123	112	133	123	101	107	109	106
	2	117	122	107	115	104	108	130	114
	3	97	92	108	99	85	91	104	93
	4	91	90	108	96	62	73	72	69
11.12.77 to 23.1.78	1	101	87	97	95	107	95	106	103
	2	104	126	76	102	97	109	198	135
	3	69	60	71	67	72	64	83	73
	4	78	64	63	68	49	61	55	55

Period of Collection		EAST				WEST			
		a	b	c	$\bar{x}$	a	b	c	$\bar{x}$
23.1.78 to 10.3.78	1	201	167	194	187	290	305	264	286
	2	188	158	145	164	377	377	555	436
	3	92	87	103	94	158	153	170	160
	4	77	66	73	69	70	94	110	91
10.3.78 to 27.4.78	1	16.5	8.4	7.3	11	138.0	204.4	141.2	161
	2	7.7	7.8	8.4	8	119.1	139.7	109.7	123
	3	5.6	6.4	8.2	7	9.7	5.3	11.2	9
	4	4.4	16.7	4.2	8	7.7	6.7	26.6	14
29.7.78 to 23.9.78	1	46.9	25.2	23.9	32	82.3	75.7	40.0	66
	2	22.7	38.6	30.3	31	49.8	39.2	95.5	61.5
	3	18.0	21.1	19.2	19.4	43.3	14.8	22.6	26.9
	4	19.7	15.5	17.0	17.4	17.1	47.6	17.9	27.5
23.9.78 to 7.10.78	1	191.3	9.2	23.2	74.5	4.2	21.1	10.9	12
	2	19.4	6.9	7.4	11.2	5.9	14.3	10.4	10.2
	3	19.5	19.4	24.0	20.9	3.0	7.8	5.0	5.2
	4	15.1	15.6	14.3	15.0	9.8	3.9	9.0	7.5
7.10.78 to 25.10.78	1	30.0	39.4	43.1	37.5	36.0	41.1	42.2	39.6
	2	41.6	36.5	37.9	38.6	33.3	25.1	22.0	26.8
	3	35.3	26.2	36.3	32.6	14.2	13.9	10.8	12.8
	4	29.7	29.6	43.2	34.1	2.8	7.0	6.9	5.5
25.10.78 to 8.11.78	1	104	210	189	168	374	408	418	400
	2	200	165	162	176	496	484	463	481
	3	92	91	73	85	243	248	233	241
	4	56	57	72	62	92	121	171	128
8.11.78 to 22.11.78	1	24.6	30.4	28.5	27.8	8.6	9.3	8.7	8.9
	2	22.9	13.0	14.4	16.8	13.6	9.2	11.0	11.3
	3	15.2	15.3	18.3	16.3	4.7	4.4	4.0	4.4
	4	7.6	8.7	12.8	9.7	1.5	4.3	3.9	3.2
22.11.78 to 6.12.78	1	14.0	55.8	135.3	68.4	2.3	3.2	7.0	4.2
	2	76.6	110.3	10.0	46.0	2.3	2.8	5.6	3.6
	3	23.8	18.8	36.2	26.3	0.8	0.6	0.4	0.6
	4	50.4	126.5	92.6	89.8	1.2	1.6	2.9	1.9
6.12.78 to 20.12.78	1	214	418	386	339	66	69	65	67
	2	333	359	304	332	56	61	70	62
	3	244	264	317	275	51	46	42	46
	4	221	218	265	235	22	26	30	26
20.12.78 to 24.1.79	1	302	794	740	612	78	141	87	102
	2	744	718	727	730	113	128	122	121
	3	472	620	692	595	135	139	153	142
	4	533	455	698	562	142	156	211	170
24.1.79 to 2.3.79	1								
	2								
	3								
	4								
2.3.79 to 2.4.79	1	108.9	52.8	47.8	69.8	14.2	25.6	24.4	21.4
	2	97.2	155.9	72.6	108.6	14.0	9.9	10.5	11.5
	3	44.1	76.1	113.8	78.0	16.7	12.5	12.1	13.8
	4	113.8	134.0	77.0	108.3	7.9	9.1	13.2	10.1
2.4.79 to 27.4.79	1	22.3	23.5	26.9	24.2	10.4	12.5	10.4	11.1
	2	30.3	36.8	26.8	22.3	10.1	11.9	12.6	11.5
	3	25.6	23.8	24.9	24.8	9.9	9.5	10.6	10.0
	4	26.0	23.2	36.0	28.4	7.8	11.2	9.2	9.4
1.6.79 to 6.7.79	1	11.5	4.5	11.2	9.1	9.5	9.0	29.9	16.1
	2	33.9	7.2	4.9	15.3	17.3	11.3	18.2	12.3
	3	66.0	89.0	6.0	53.7	14.7	4.9	10.2	9.9
	4	10.3	17.5	104.0	43.9	12.8	8.2	6.3	9.1
6.7.79 ti 27.7.79	1	7.4	8.0	12.2	9.2	16.4	23.2	43.9	27.8
	2	36.5	19.7	10.2	22.1	12.0	16.1	21.5	16.5
	3	26.9	25.0	22.0	24.6	13.7	13.0	11.0	12.6
	4	20.0	19.1	14.1	17.7	14.1	16.0	23.9	18.0

APPENDIX 2

ANALAYSIS OF THE SALTATION COMPONENT PRODUCED BY WIND EROSION OF SLIME DUMPS AT KALGOORLIE

APPENDIX 2

THE SALTATION COMPONENT PRODUCED BY WIND EROSION OF SLIME DUMPS AT KALGOORLIE

D.Carter - Department of Agriculture

INTRODUCTION

One of the major contributors to the dust problem in Kalgoorlie over the last eighty years has been the dry tailings (slime) dumps to the west of the town.[2] These dumps generate considerable dust when erosive winds blow from the south-east quarter. A special committee, the Goldfields Dust Abatement Committee which was representative of the local authorities and State Government Departments in Kalgoorlie, was established to investigate and combat the dust problem. From this committee's activities, Dr. J. Marshall was consulted and a plan was put into operation to prevent dust lift off from the dumps.[1] This plan involved spreading a layer of rocks over the dump surface in such a way as to prevent saltation[1] and therefore prevent abrasion and lift-off of the dust.

The above study was reported to reduce saltation by approximately 80-90 percent in moderate to severe wind erosion events. The report, however, did not comment on the relationships between the dump surface and climatic conditions existing during the trial period. It is the aim of this paper to present the climatic information gathered during the pre-treatment monitoring phase (September 1976 to January 1977) and the treatment phase (February 1977 to January 1979) on Chaffer's dump.

Chaffer's Dump

From the report on the soils and plants of the tailing dumps[5], the physical, chemical and biological characteristics of Chaffer's dump are presented in Table 1. The dump occupies a total area of 40 hectares and is divided into an east and west section. These two areas were sampled each in four locations by three saltation gauges. The West Chaffer's dump was partially covered with rocks prior to February 1977 and was monitored by the gauges West 3 and 4. The gauges, West 1 and 2, monitored an untreated area and remained as controls throughout the whole of the sampling periods from 1976 to 1979.

The East Chaffer's dump was wholly treated with rocks prior to the sampling period beginning in July 1977.

METHODS

Saltation Samples

The saltation samples were collected in unidirectional soil collectors designed by Dr. Marshall[1] which sampled an arc of 115°. The material collected was removed whenever they were approaching full capacity. This varied from 3 to 48 days.

TABLE 1 Physical, chemical and biological characteristics. the Chaffer's dump, Kalgoorlie (taken from [1]).

	West Chaffer's	East Chaffer's
No. years surface exposed	16	8
Average elevation (m)	18	24
Angle of greatest slope	2	0
Plant growth	0	0
% sand (av.)	60	66
% silt	30	26
% clay	10	8
Bulk density g/cc	1.00	1.30
Available WHC*	21	17
Dust potential**	20	22
pH	7.2	7.3
Total sol. salts meg/l	95	⩾ 155
Cl^- meg/l	100	182

Note: * WHC is the available water holding capacity. This is equal to the field capacity minus the permanent wilting point. It is expressed as grams water per 100 grams of soil.

** Dust potential as defined by Lamont[5].

The sampling program was consistent but not continuous from 1976 to 1979, because of the stoppages due to the preparation of the dumps prior to the rock spreading, and also the winter collections were discontinued because of difficulties in keeping water out of the sampling bags.

Meteorological Data

The data on daily rainfall, wind velocity, humidity and temperature were supplied by the Kalgoorlie Meteorology Station, which is situated at the Kalgoorlie aerodrome approximately 5 kilometres from the slime dumps. No weather records on the dumps themselves were taken.

The wind velocity data were transposed from Dynes anemometer tracings of continuous instantaneous wind velocities. In the time available, the traces could not be integrated by machine and therefore the approximate mean velocities were integrated by eye. The arc of wind direction was from 70^{o} to 180^{o} from north and velocities of less than 10 knots were discarded. The wind velocity for correlations with saltation levels was computed by the equation:

$$\Sigma (V - V_t)^3 .t$$

where V was mean integrated velocity (m/sec), V_t was the threshold velocity (5.26 m/sec), t was time interval of V (10). These values were computed on a daily basis and also summed for each of the saltation sampling periods.

Results

In Table 2, the mean saltation figures are given for the twenty-one sampling periods, where the saltation is expressed in terms of total weight of material collected in the gauges. For a comparison between the sampling periods which differ in duration, the saltation has been calculated in terms of saltation across 3.8 centimetres (the width of the opening in the saltation gauge) per day[1] and is shown in Table 3. In this table, the reduction in saltation between the treated and untreated areas in the West Chaffer's dump for each sampling period is given.

The major periods of saltation were during the summer months when the weather was hot and dry. Throughout the three years of sampling, no significant movement of the saltation materials occurred until about December or January for each year. The preceding months had either enough rainfall to stop the wind erosion or there was enough residual moisture in the dump from the winter rains to prevent saltation.

The highest amount of saltation recorded was 46.4 gm cm^{-1} day^{-1} which occurred in the East Chaffer's dump in March 1977. Since that time of severe erosion, the amount of saltation has not approached that figure; the next highest being 8.27 gm cm^{-1} day^{-1} (disregarding the saltation figures of April 1977) for November 1978.

The decrease in erosion may be a reflection in the change of annual rainfall between these years. The average rainfall for Kalgoorlie is 230 millimetres and the totals for 1976, 1977 and 1978 were 127, 153 and 212 millimetres respectively. The saltation occurring in the control area over the whole sampling period is given in Figure 1.

The meteorological data of wind velocity, humidity, temperature and daily rainfall has been presented in Figures 2, 3 and 4. The pre-treatment phase was interdispersed with rain and only in the last sampling period were any significant saltation samples collected. This collection was most probably due to either the wind events from 22-26 December 1977 or 4-6 January 1978. The latter, however, may have been affected by the 4 millimetres of rain on December 30 (Fig. 2). It is only speculation on how much and for how long this rain affected the dump surface.

During the intense period of erosion from 5 February to 5 March 1977, no rain was recorded at the Kalgoorlie Meteorology Bureau, thus allowing the dump surface to be at its most erodible (Tables 2, 3). This sampling period was also the start of the monitoring phase of the rock mulch treatment, and it can be clearly seen that the rock spreading on West Chaffer's (3, 4) had significantly reduced the saltation. This has been more fully reported by Marshall et. al.[1] The wind events occurring throughout this period were generally of one day duration, the maximum being 309 units on the $(V-V_t)^3$ scale. However, the highest saltation value was produced by the wind event on 22 February with a rating of 206 units. The apparent anomaly of a lesser wind event producing more saltation than the previously monitored event is discussed later when considering the availability of erodible materials.

No rain was recorded during the sampling period in July 1977 and the amount of saltation was very low, even though there was a strong wind event during this period. This low erosion rate would undoubtedly have been due to the higher rainfall that reduced the wind erosion hazard during the winter months.

The complete meteorological data after April 1978 could not be obtained and the information about the sampling periods after 1 April has not been presented.

The saltation rate was compared to the wind speed cubed factor in a regression analysis in the form of :

$$Y = A + BX$$

where Y was saltation and X was $\Sigma\ (V - V_t)^3.t$.

The R^2 value was 0.003, which indicated no relationship at all. When the data in Figures 2, 3 and 4 were looked at closely in order to eliminate those days when it was windy but no erosion occurred, a better relationship was obtained, viz:

$$Y = 13.5 + 1.8X$$

$$R^2 = 0.92$$

The values for X are presented in Table 4. In this analysis, the sampling periods of Nos. 10, 12 and 13 were omitted because they were thought to be quite different from the other sampling period. Also, all days with recorded wind that occurred within four days of rainfall were omitted because this period of time allowed for the drying of the dump surface so that saltation could occur.

The above equation has shown a good correlation between the carrying capacity of the wind and the total amount of saltating materials, but the validity of the result is suspect due to the subjectivity in omitting some of the data. It did, however, show the necessity to have much smaller sampling periods for any correlation to be obtained.

Discussion

The amounts of saltation material collected during each sampling period from 1976 to 1978 did not correlate in any obvious way with the meteorological data, other than a reduction in saltation due to rain. This lack of correlation was undoubtedly due to the large sampling periods and the consequent masking of those days which actually contributed to the bulk of the saltation. Even the days which recorded rain may have contributed some wind erosion before the rain fell. However, this was indeterminable from the data available.

TABLE 2 Chaffer's dump : mean saltation for east and west portion of dump : sampling periods 1976 to 1979.

Sampling Period	Date	Mean Saltation in gms wt.				No. Days Sampled
		$E_{1,2}$	$E_{3,4}$	$W_{1,2}$	$W_{3,4}$	
1	27. 9.76 - 8.10.76	5.1	7.8	52.5	63.9	11
2	8.10.76 - 14.11.76	28.3	27.4	33.5	48.5	37
3	14.11.76 - 27.11.76	33.0	46.6	17.4	19.7	12
4	27.11.76 - 19.12.76	4.5	27.7	59.1	54.3	21
5	19.12.76 - 8. 1.77	325.0	385.0	464.0	546.0	19
6	5. 2.77 - 16. 2.77	620.0	502.0	433.0	42.0	11
7	16. 2.77 - 22. 2.77	220.0	270.0	296.0	47.0	5
8	22. 2.77 - 25. 2.77	516.0	538.0	502.0	134.0	3
9	25. 2.77 - 5. 3.77	636.0	629.0	572.0	135.0	7
10	15. 9.77 - 26. 9.77	11.4	11.7	7.5	3.8	11
11	15.11.77 - 11.12.77	119.0	98.0	110.0	81.0	26
12	11.12.77 - 23. 1.78	98.0	67.0	119.0	64.0	44
13	23. 1.78 - 10. 3.78	176.0	83.0	361.0	126.0	46
14	10. 3.78 - 27. 4.78	9.3	7.6	142.0	11.2	47
15	29. 7.78 - 23. 9.78	31.0	18.4	64.0	27.0	56
16	23. 9.78 - 7.10.78	43.0	18.0	11.1	6.4	14
17	7.10-78 - 25.10.78	38.0	33.0	33.2	9.2	18
18	25.10.78 - 8.11.78	172.0	73.5	440.5	185.0	14
19	8.11.78 - 22.11.78	22.0	13.4	10.6	4.1	14
20	22.11.78 - 6.12.78	67.0	58.0	3.9	1.2	14
21	6.12.78 - 20.12.78	336.0	254.5	64.5	36.0	14
22	20.12.78 - 24. 1.79	670.0	578.0	112.0	156.0	35

TABLE 3 Chaffers E/W saltation reductions.

Sampling Period	Date	Saltation in gm, cm^{-1} day^{-1}				% Saltation Reductions
		$E_{1,2}$	$E_{3,4}$	$W_{1,2}$	$W_{3,4}$	
1	27. 9.76 - 8.10.76	0.1	0.2	1.2	1.4	-
2	8.10.76 - 14.11.76	0.2	0.2	0.2	0.3	-
3	14.11.76 - 17.11.76	0.7	0.9	0.4	0.4	-
4	27.11.76 - 19.12.76	0.5	0.3	0.7	0.7	-
5	19.12.76 - 8. 1.77	4.3	5.1	6.1	7.2	-
6	5. 2.77 - 16. 2.77	13.6	12.8	9.3	0.9	92
7	16. 2.77 - 22. 2.77	9.6	23.7	13.0	2.0	84
8	22. 2.77 - 25. 2.77	45.2	46.4	44.0	11.7	73
9	25. 2.77 - 5. 3.77	20.9	20.7	18.8	4.4	77
10	15. 9.77 - 26. 9.77	0.2	0.3	0.2	0.1	47
11	15.11.77 - 11.12.77	1.2	1.0	1.1	0.8	26
12	11.12.77 - 23. 1.78	0.5	0.4	0.7	0.4	46
13	23. 1.78 - 10. 3.78	1.0	0.5	2.0	0.7	65
14	10. 3.78 - 27. 4.78	0.05	0.04	0.8	0.1	92
15	29. 7.78- 23. 9.78	0.1	0.1	0.3	0.1	57
16	23. 9.78 - 7.10.78	0.8	0.3	0.2	0.1	43
17	7.10.78 - 25.10.78	0.5	0.5	0.5	0.1	72
18	25.10.78 - 8.11.78	3.2	1.4	8.3	3.5	58
19	8.11.78 - 22.11.78	0.4	0.2	0.2	0.1	61
20	22.11.78 - 6.12.78	1.3	1.1	0.1	0.02	71
21	6.12.78 - 20.12.79	6.3	4.8	1.2	0.7	43
22	20.12.79 - 24. 1.79	5.0	4.3	0.84	1.17	-39

* % reduction in saltation =

$$\left(1 - \frac{\text{Saltn } W_{3,4}}{\text{Saltn } W_{1,2}}\right) \times 100$$

TABLE 4 Wind velocity factor when rain days were eliminated.

Sampling Period No.	$(V - V_t)^3$	Saltation $W_{1,2}$ (g)
1	31.6	52
2	30.7	34
3	38.1	17
4	21	59
5	307	464
6	240	433
7	170	296
8	207	502
9	311	572
10*	402	7.5
11	66	110
12*	650	119
13*	550	361
14	126	142

* Eliminated from regression analysis.

The controlling factors in the wind erosion of these dumps would be the moisture content of the surface, the drying rate of the surface and also to a lesser extent, the availability of erodible materials. These factors would all govern the amount of material collected in the saltation gauges.

The availability of erodible materials is an important concept controlling saltation and dust lift off the surface. Two sources of saltating materials exist in the dump environment. The first is an external source, being the accumulated sand on the steep sloping edges which has been deposited in past wind events. The second, which is locally derived, is newly abraded material from the surface of the dump itself. This second source of saltating material would be the major contributor to the dust evolution, but the first source may be an initiator of the abrasion required to detach the locally derived saltating particles.

Hence, the availability of eroding materials is important, especially when a surface crust forms on the dump and has to be abraded to produce new dust.

Another aspect of the presence of saltating materials is how it affects the performance of the stone mulch treatment and the interpretation of the results due to that treatment. It can be seen from Table 3 that there is a slight tendency for a decrease in the effectiveness of the stone mulch in preventing saltation. This is especially evident in the later sampling periods (e.g. No. 21). Two more sampling periods; 2 March-2 April and 2 April-27 April 1979 which have not been presented in Table 3, had reductions in saltation of 38% and 14% respectively. The decrease in effectiveness was due to a sand blanket building up between the stones, thus reducing the effective size of the rocks as roughness elements. When this occurred, the wind was able to cause saltation from the "new" surface. Therefore, it was possible to obtain more saltating particles on the stone treatment than on the control plots because of the greater sand accumulation on the treated areas. This situation occurred during the sampling period No. 21. The source of the sand between the rocks would have most probably come from the sides of the dump. This increase in saltation in the treated area would not necessarily mean that more dust was produced because the sand blanket should have protected the dump surface from abrasion.

Conclusions

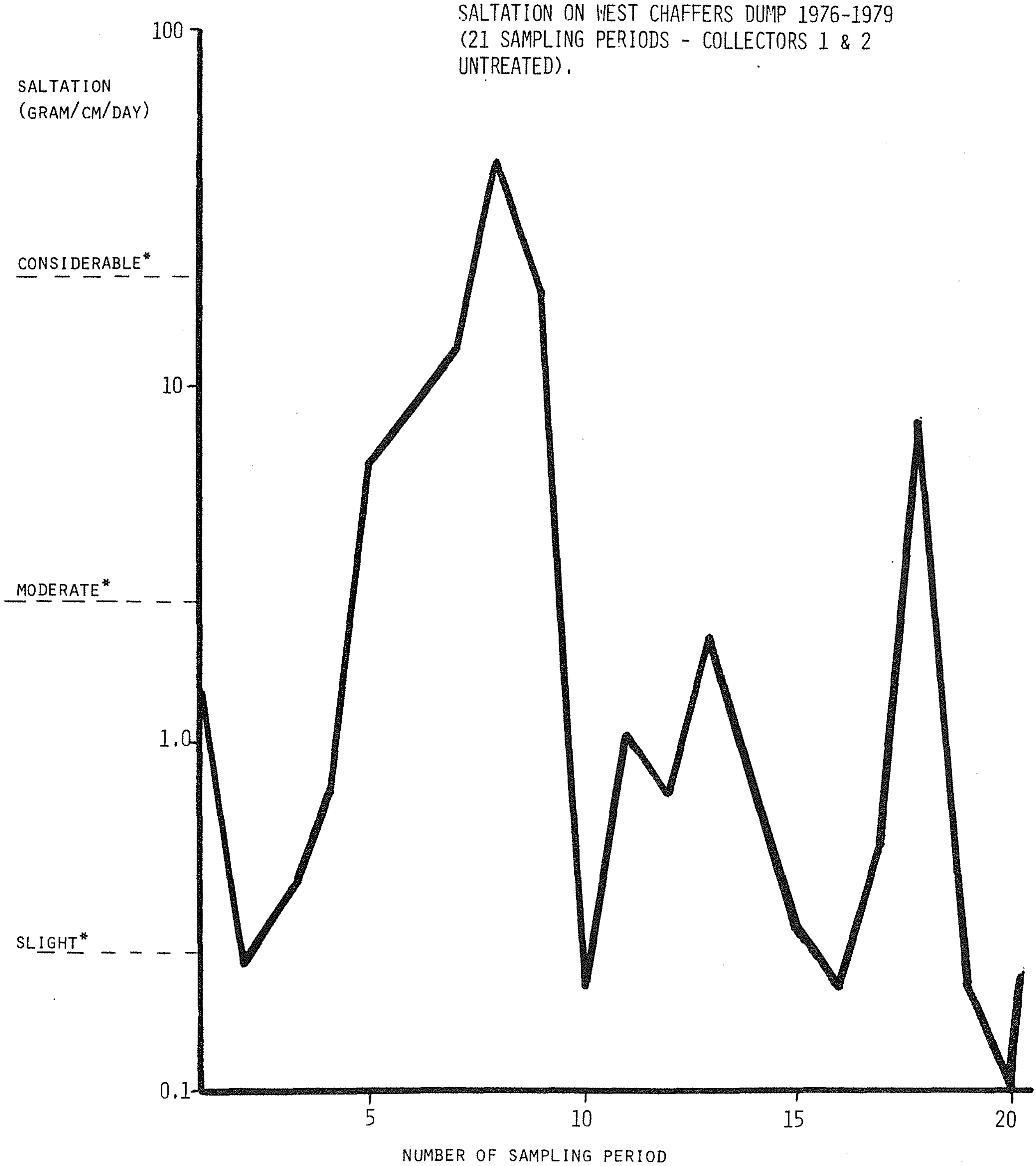
1. The saltation of sand sized materials on the dump surfaces increased during the summer months, especially as the surface dried out after the winter rains. Any rainy period during the summer months effectively reduced the level of saltation.

2. The relationship between wind velocity, daily temperatures and humidities, with saltation levels could not be established with any confidence because of the long sampling periods during the study. This made it difficult to identify the days upon which the saltation had occurred within each sampling period, especially if some rainy days occurred.

3. The reduction in the amount of saltating materials due to the rock spreading treatment decreased as the age of the treatment increased. This apparent anomaly was due to a covering of the rocks by a sand blanket that had blown into the rock treatment area from the accumulated sand at the steep edges of the dumps.

FIG. 1.

SALTATION ON WEST CHAFFERS DUMP 1976-1979
(21 SAMPLING PERIODS - COLLECTORS 1 & 2
UNTREATED).



* NOTE: THESE BROADLY QUANTITATIVE LEVELS OF SALTATION ARE TAKEN FROM THE WORK BY DR. MARSHALL AND OTHERS AT KALGOORLIE (SEE REF.NO.1)

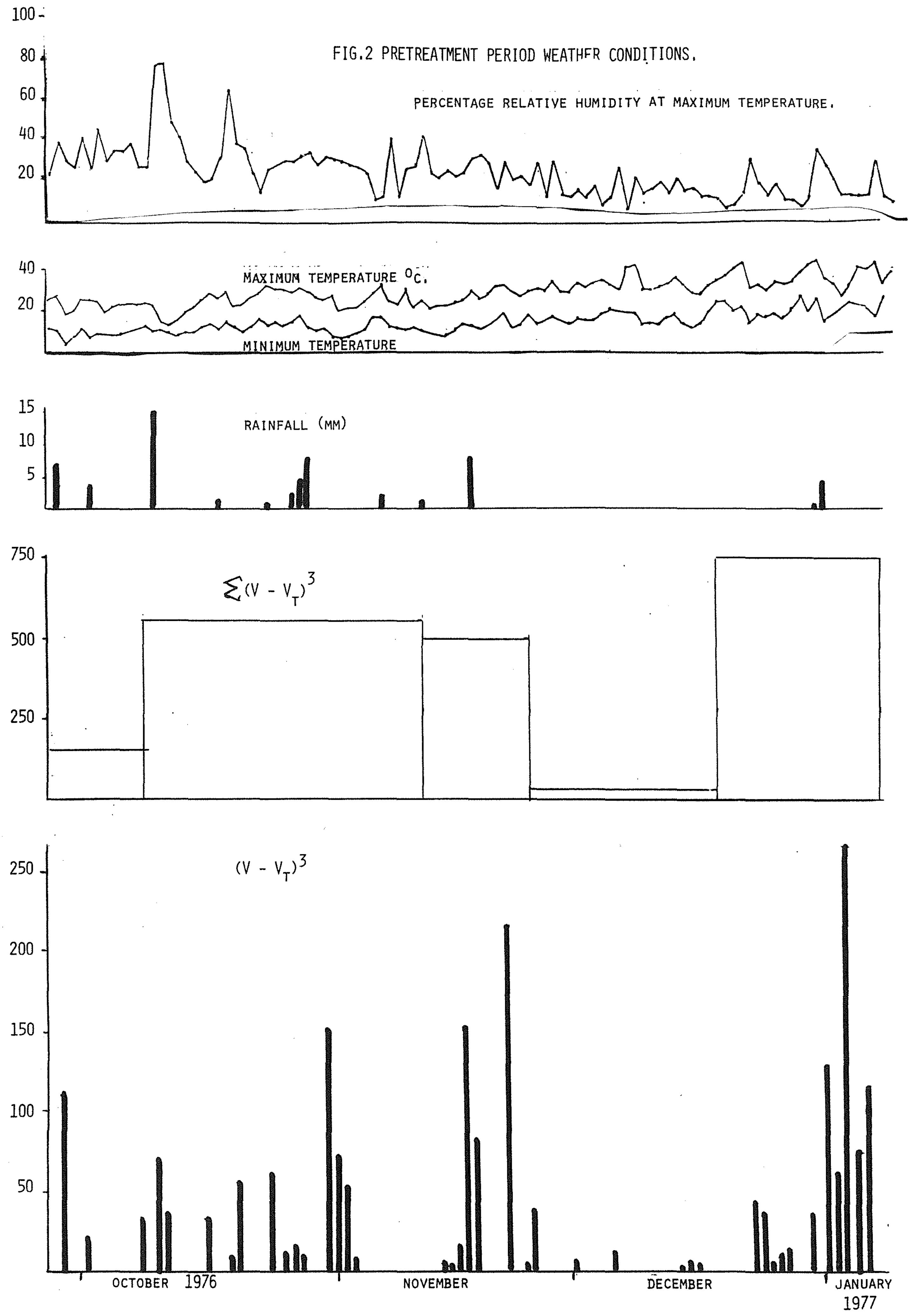


FIG.2 PRETREATMENT PERIOD WEATHER CONDITIONS.
PERCENTAGE RELATIVE HUMIDITY AT MAXIMUM TEMPERATURE.
100
80
60
40
20
MAXIMUM TEMPERATURE °C.
MINIMUM TEMPERATURE
40
20
RAINFALL (MM)
15
10
5
∑(V - V_T)^3
750
500
250
(V - V_T)^3
250
200
150
100
50
OCTOBER 1976
NOVEMBER
DECEMBER
JANUARY 1977

FIG. 3 POST TREATMENT PERIOD WEATHER CONDITIONS.
OVER FEBRUARY 1977 TO JANUARY 1978.

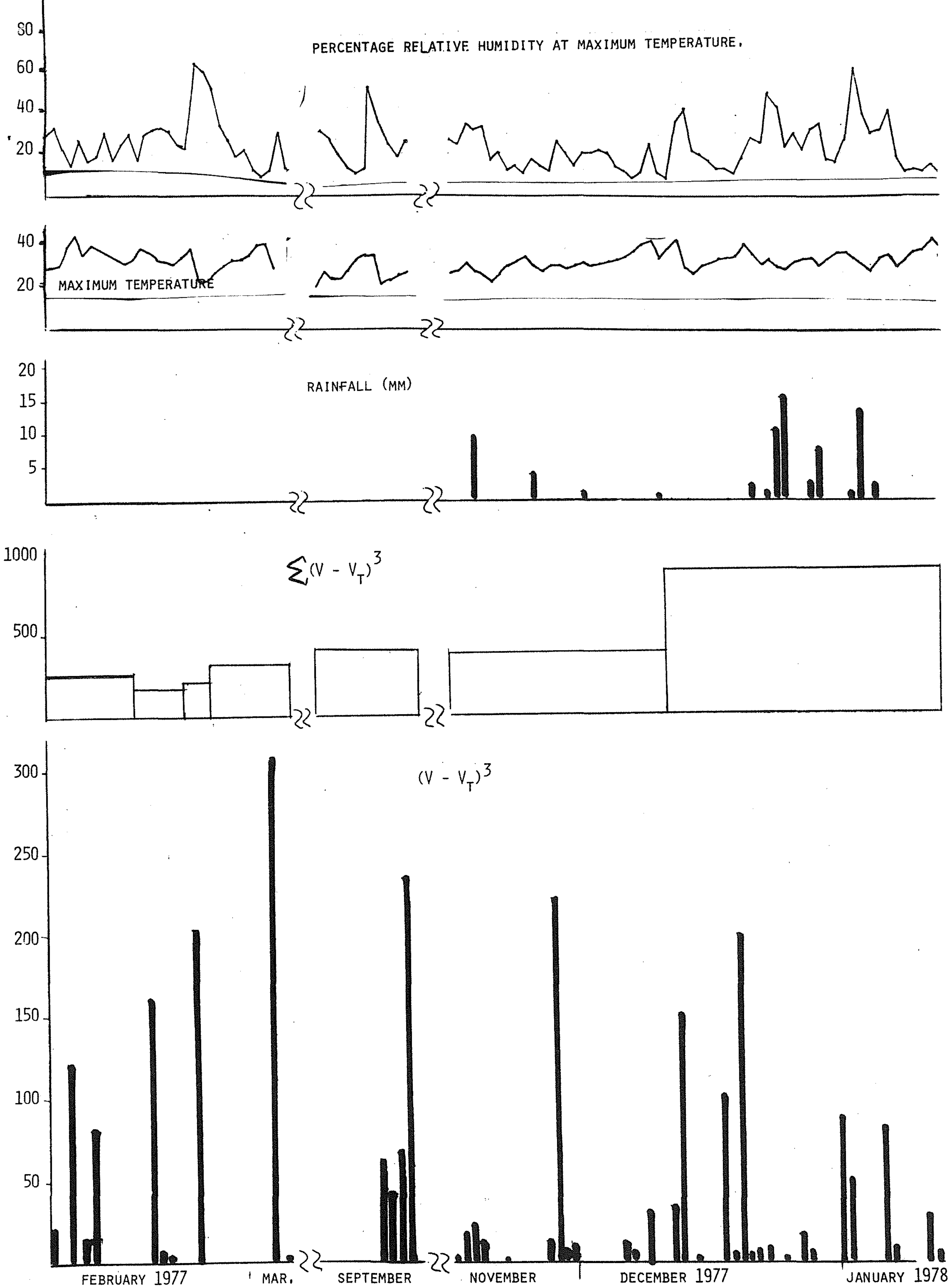
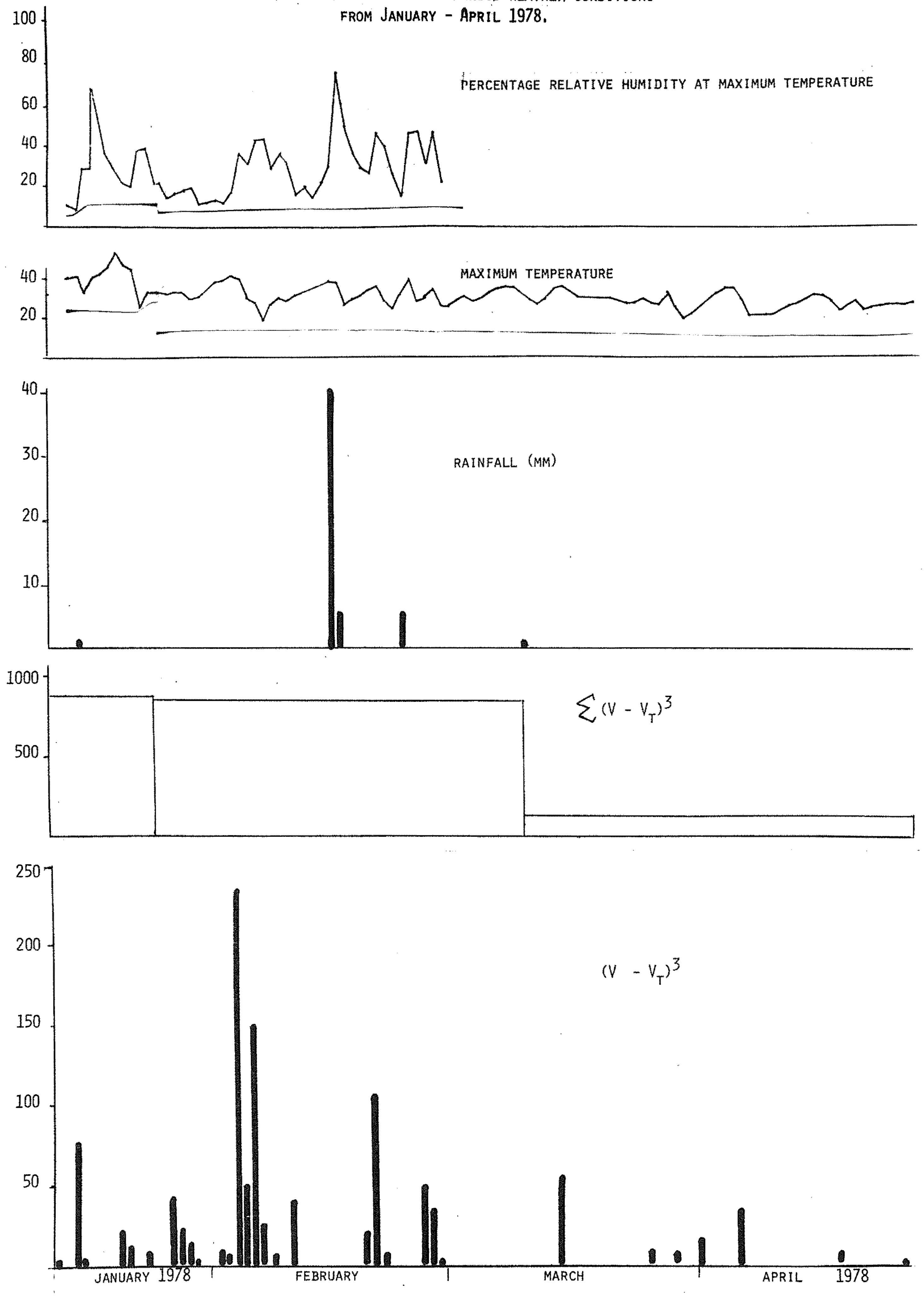


FIG.4 POST TREATMENT PERIOD WEATHER CONDITIONS FROM JANUARY - APRIL 1978.



APPENDIX 3

WIND TUNNEL RESEARCH PROPOSAL

APPENDIX 3

WIND TUNNEL RESEARCH PROPOSAL

TITLE: Bullfinch Mine : Dust Abatement.

FILE NO.: 977/76, 3626 Ex.

PERSONNEL: D.J. Carter, J.R.H. Riches

INTRODUCTION

The township of Bullfinch has been affected by crushed ore dust blowing over the town from the slime dumps north-east of the township. A method of preventing these dust storms has been proposed by Dr. J.K. Marshall (CSIRO, Division of Land Use Research), which involves the spreading of mullock (stones of approximately 10 cm diameter) over the surface of the dump. From the theory of aerodynamics of rough surfaces, the stones prevent the saltation of sand-size particles which, in turn, would stop the abrasion of the fine surface that generates the dust. This scheme has been used in Kalgoorlie where saltation has been reduced by up to 85 per cent; however dust samples were not taken, therefore the success of this method in dust abatement was not tested.

OBJECT OF THE STUDY

The project will look at the ability of the stone covering to prevent dust generation from the surface of the slime dump material. It is proposed to make an artificial bed of the material from Bullfinch set up as experimental plots at South Perth. This will enable a more frequent monitoring and better moisture control of the dump material than would otherwise be possible at Bullfinch. The erodibility of the surface would be determined by use of a portable wind tunnel.

Another objective is to obtain basic physical information about the slime dump material and how its surface morphology changes with salinity, and also wetting and drying cycles.

SITE AND LOCALITY

An area of land (approximately 200 m^2) will be required in the experimental plot area at the Department of Agriculture, South Perth. It is envisaged to use the experimental site previously used by I. Laing for runoff studies.

PLOT LAYOUT

Four plots with dimensions of 7 x 1.8 m will be laid out as in Diagram 1. An access track of 3 m width will be required at one end of the plots for the wind tunnel and trailer. The depth of the slurry will be approximately 20 cm, therefore about 15 tonnes of slime dump material will be required (the bulk density of the dump is approximately 1.5 gm/cc or less). The four plots will be side by side and separated by galvanised iron dividers.

TREATMENTS

1. Contral plot - no treatment.

2. Stone mullock at 40 tonnes/ha will be randomly scattered on the surface (average stone size 100 mm).

3. Same as 2, but accretion material (wind blown sandsize particles) spread between stone mullock to a depth of 1 cm.

4. Spheres (100 mm diameter) placed on the surface precisely 3¼ x diameter of the spheres distant from each other in a regular grid pattern rotated through 45^{o} to the direction of the wind tunnel. This treatment is the "ideal" spacing to prevent saltation (J.K. Marshall, pers. comm.).

METHODS

1. Preparation of the plots

   The slime dump material will be transported from Bullfinch by courtesy of the Department of Conservation and Environment. The relatively dry material will need to be slurried with saline water (to be determined) and spread out into the prepared sites. The site preparation will involve rotary hoeing the old clay plots from I. Laing's experiment and compacting this and the underlying sand to provide a solid base to the mine dump material.

   Weed growth in the base will be controlled by a residual herbicide.

   The plots will be side by side and separated by galvanised sheet iron at least 30 cm in depth. The thickness of the slurry will be approximately 20 cm and the pouring of this into the plot bed will be achieved either from a large concrete mixer or directly from a tipping tray of the transport truck. The plots will be required for at least one year, depending on the number of treatments required to provide the information sought.

   Preliminary investigations into the physical character of the Bullfinch material (in situ or from undisturbed core samples) will be required. This will indicate what sort of compaction, infiltration rates and salinity levels are necessary to duplicate the in situ dump characteristics.

2. Wind erodibility tests

   The wind erodibility tests will be carried out on the four plots and after the treatments have been applied. Since the surface of the dumps change dramatically, depending on the salt and water contents of the surface, and this in turn affects the wind erodibility, the wind tunnel will be used on the surfaces with varying moisture contents.

3. Protection of the plots

The plots have to be protected from fortuitous rain events so that some control over the moisture status of the slime dump material can be obtained. This could be achieved with erection of plastic tents over the plots.

DATA ACQUISITION

1. Preliminary study of slime dump material collected from Bullfinch.

   (a) pH, TSS, Cl levels.

   (b) Mechanical analysis; dry elutriation for particle size analysis.

   (c) Soil cores (15 cm deep) and bulk samples

      i) compaction by penetrometer readings;
      ii) infiltration rate and leaching of salt;
      iii) evaporation rate and salt accumulation at soil surface;
      iv) bulk density and particle density;
      v) moisture holding characteristics;
      vi) water stability of the material.

2. Wind erodibility.

   (a) level of saltation;

   (b) amount of suspended material (dust);

   (c) variation of erodibility with

      i) salt content;
      ii) moisture content;
      iii) surface condition;
      iv) wind speed.

3. Surface morphological changes.

   (a) ground-based stereophotography.

   (b) deflation during erosion (truncometer measurements).

DATA USE

1. The preliminary data obtained from Bullfinch will be necessary in the installation of the plots at South Perth so that they will be comparable to the original material. The data will also provide basic information for the understanding of the dynamic nature of the surface of the crushed ore dumps.

2. The wind tunnel will provide information on the influence of the treatments in preventing dust lift-off from the dump surfaces.

3. The stereo photography will enable accurate assessment of the dynamic nature of the dump surface during its changing moisture regimes and during erosion cycles.

MATERIALS

Area of land required - 72.0 m^2

single plot - 12.6 m^2

block - 50.4 m^2

Slime dump material approximately 15 tonnes (assuming bulk density of 1.0 g/cc).

Plot protection - framework for tent; heavy duty black plastic as the shelter material.

Border material - 30.0 cm wide galvanised sheet metal cut to the appropriate length, 49.4 m in total length.

Stone mullock - Bullfinch 1.6 tonnes of approximately 100 mm diameter crushed rock.

Saltated material from Bullfinch approximately 100 kg.

PERSONNEL

Plot preparation	2 technicians	D.R.M.	2 days
Wind tunnel work	2 technicians	D.R.M.	6 days
Bullfinch sampling	1 technician	D.R.M.	1 day
Photography	1 technician	D.R.M.	1 day
Laboratory work	1 technician		10 days

AREAS OF RESPONSIBILITY

Plot preparation
Wind tunnel work
Bullfinch sampling
Photography
Laboratory work
Paper work

D.J. Carter

Slime dump material from Bullfinch - R. Nunn, DCE.

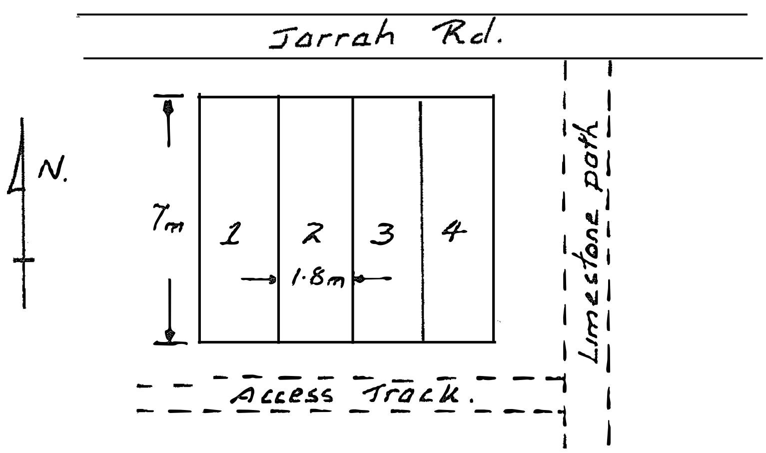


DIAGRAM 1

APPENDIX 4

CERL DUST MEASUREMENTS FROM BULLFINCH - AS BOTH WEIGHT OF DUST IN MILLIGRAMS AND IN UNITS OF TOTAL DIRTINESS

DUST MEASUREMENTS WITH CERL DUST GAUGES
ON THE COPPER HEAD SLIME DUMP, BULLFINCH.

GAUGE NO. 1

DATE	OBSCURATION UNITS				WEIGHT OF SAMPLES (MILLIGRAMS)			
	W	S	E	N	W	S	E	N
24.10.78								
28.11.78	10 000	12 500	9 500	6 000	5 640	4 180	19 200	3 590
19.12.78	3 455	4 400	22 500	5 500	2 670	7 070	23 900	7 390
15. 1.79	3 500	1 600	9 000	7 750	4 480	2 350	15 850	10 270
12. 2.79	1 150	3 100	22 500	4 250	2 270	6 110	33 360	4 940
28. 2.79	833	915	2 360	285	1 020	930	3 630	310
13. 3.79	850	700	7 250	17 500	260	320	5 780	1 890
23. 3.79	38 250	1 650	1 200	2 100	29 400	890	970	1 750
11. 4.79	1 064	505	8 150	-	970	460	8 260	-
10. 5.79	642	250	248	348	1 210	410	230	430
7. 6.79	295	725	185	235	270	1 100	80	180
5. 7.79	49	42	18	29	40	20	4	5
2. 8.79	8 750	2 500	365	575	4 940	1 890	300	-
30. 8.79	315	100	645	240	500	150	320	220
4.10.79	1 330	3 050	1 350	1 150	1 350	8 140	450	300
28.10.79	600	250	1 700	2 550	460	270	2 200	2 860
7.11.79	750	950	2 750	4 600	90	290	1 870	3 540
3.12.79	6 250	3 100	8 000	7 750				
21.12.79	2 415	13 300	1 400	4 900	5 180	31 780	1 670	2 870
2. 1.80	3 050	1 150	9 300	4 900	3 350	890	11 720	2 830
17. 1.80	3 000	1 700	5 000	5 280	3 250	2 160	5 130	3 850
1. 2.80	250	345	5 500	950	370	510	10 130	1 850
13. 2.80	1 150	1 050	1 500	3 050	520	1 290	-	3 090
29. 2.80	305	250	6 250	510	310	310	4 570	1 040
11. 3.80	650	550	200	1 650	600	1 290	240	1 810
28. 3.80	850	900	8 000	1 000	1 470	1 200	8 640	830

GAUGE NO. 2

DATE	OBSCURATION UNITS				WEIGHT OF SAMPLES (MILLIGRAMS)			
	W	S	E	N	W	S	E	N
24.10.78								
28.11.78	5 500	2 100	8 750	6 500	4 300	1 410	10 650	3 510
19.12.78	2 450	2 500	30 700	7 000	2 290	2 610	16 820	6 690
15. 1.79	3 900	850	8 750	12 500	3 330	1 230	9 830	14 220
12. 2.79	1 750	1050	5 500	3 050	1 770	2 800	10 530	3 910
28. 2.79	1 915	760	1 920	765	1 270	480	4 180	250
13. 3.79	1 050	1 150	6 500	19 000	190	280	1 520	2 590
23. 3.79	13 000	450	550	750	14 450	220	440	1 680
11. 4.79	785	463	5 370	7 000	800	620	7 460	7 700
10. 5.79	750	164	305	405	1 330	160	230	540
7. 6.79	255	320	146	275	230	490	70	280
5. 7.79	55	38	37	30	80	70	20	20
2. 8.79	11 500	950	94	150	3 860	980	160	220
30. 8.79	200	59	464	365	330	90	450	270
4.10.79	1 450	1 800	1 000	800	1 380	2 450	400	290
28.10.79	200	50	1 200	2 650	300	240	1 620	3 250
7.11.79	1 300	700	2 650	3 100	200	180	2 820	2 140
3.12.79	1 950	1 500	6 000	4 750				
21.12.79	2 030	2 205	560	3 605	2 600	3 810	810	3 280
2. 1.80	1 150	650	4 600	1 450	1 210	540	6 460	1 730
17. 1.80	1 100	550	3 500	3 500	1 680	900	5 170	4 040
1. 2.80	365	450	3 750	910	460	760	6 500	1 850
13. 2.80	1 440	920	7 000	3 100	830	730	12 560	2 520
29. 2.80	190	205	1 850	715	190	160	3 030	-
11. 3.80	350	300	150	2 000	530	540	360	1 170
28. 3.80	1 250	850	6 250	1 150	730	640	5 510	620

GAUGE NO. 3

DATE	OBSCURATION UNITS				WEIGHT OF SAMPLES (MILLIGRAMS)			
	W	S	E	N	W	S	E	N
24.10.78								
28.11.78	800	1 200	6 500	7 500	400	1 700	4 170	4 110
19.12.78	1 350	1 450	3 750	7 500	940	950	10 840	9 130
15. 1.79	950	650	8 000	10 000	1 070	810	8 110	14 920
12. 2.79	900	650	5 000	3 900	720	900	5 310	4 740
28. 2.79	1 310	222	544	405	1 390	200	190	490
13. 3.79	165	200	945	640	90	200	1 070	2 360
23. 3.79	3 400	550	900	1 800	1 670	220	240	1 060
11. 4.79	555	615	4 020	6 240	620	570	5 140	8 430
10. 5.79	275	99	202	605	260	60	170	600
7. 6.79	117	110	176	365	60	90	180	360
5. 7.79	30	13	26	16	20	10	10	8
2. 8.79	200	28	31	59	350	150	40	90
30. 8.79	95	56	240	408	100	70	280	460
4.10.79	106	350	504	615	60	290	240	440
28.10.79	650	450	4 500	7 000	930	970	6 650	11 770
7.11.79	750	1 250	3 400	7 500	60	250	5 150	-
3.12.79	1 800	1 600	5 000	6 250				
21.12.79	490	2 065	560	3 500	510	1 060	530	2 930
2. 1.80	500	300	1 600	1 900	550	270	1 710	2 470
17. 1.80	485	225	2 160	3 900	730	460	2 220	4 290
1. 2.80	220	180	-	1 300	200	230	-	2 120
13. 2.80	1 120	800	-	4 450	550	450	-	4 790
29. 2.80	160	140	850	1 400	330	110	1 640	910
11. 3.80	400	200	150	2 050	130	430	310	2 570
28. 3.80	700	650	7 750	2 250	60	120	3 510	1 800

DUST MEASUREMENTS WITH CERL DUST GAUGES
ON THE COPPER HEAD SLIME DUMP, BULLFINCH.

GAUGE NO. 4

DATE	OBSCURATION UNITS				WEIGHT OF SAMPLES (MILLIGRAMS)			
	W	S	E	N	W	S	E	N
24.10.78								
28.11.78	90	130	138	137	40	110	90	140
19.12.78	25	52	66	1000	120	120	150	340
15. 1.79	105	399	302	654	150	650	420	820
12. 2.79	31	72	90	266	90	70	80	320
13. 3.79	74	55	61	90				
11. 4.79	170	213	88	355				
10. 5.79	44	23	29	51				
7. 6.79	32	44	45	51				
5. 7.79	29	36	30	22				
2. 8.79	60	39	22	34				
30. 8.79	32	69	47	56				
4.10.79	35	140	59	80				
1.11.79	68	135	40	250				
3.12.79	130	660	65	259				
2. 1.80	51	485	88	130				
1. 2.80	33	140	105	160				
29. 2.80	16	32	24	105				
11. 3.80	-	-	-	-				
28. 3.80	100	130	78	125				

GAUGE NO. 5

DATE	OBSCURATION UNITS				WEIGHT OF SAMPLES (MILLIGRAMS)			
	W	S	E	N	W	S	E	N
24.10.78								
28.11.78	61	84	132	42	40	30	60	30
19.12.78	26	66	55	110	50	100	110	210
15. 1.79	90	82	120	200	260	200	90	390
12. 2.79	36	42	78	111	30	40	20	90
13. 3.79	33	41	29	26				
11. 4.79	112	47	42	136				
10. 5.79	16	26	15	20				
7. 6.79	22	29	19	17				
5. 7.79	19	12	19	6				
2. 8.79	51	30	18	23				
30. 8.79	29	20	31	36				
4.10.79	42	90	37	51				
1.11.79	40	35	5	65				
3.12.79	40	43	11	60				
2. 1.80	38	237	26	58				
1. 2.80	51	62	49	150				
29. 2.80	46	0	20	36				
11. 3.80	-	-	-	-				
28. 3.80	31	43	29	57				

GAUGE NO. 6

DATE	OBSCURATION UNITS				WEIGHT OF SAMPLES (MILLIGRAMS)			
	W	S	E	N	W	S	E	N
24.10.78								
28.11.78	37	44	17	64	20	20	10	30
19.12.78	12	30	39	90	130	120	30	110
15. 1.79	81	42	86	151	130	90	40	150
12. 2.79	41	62	80	54	70	20	40	100
13. 3.79	52	47	90	34				
11. 4.79	120	69	38	167				
10. 5.79	46	37	44	25				
7. 6.79	39	37	15	26				
5. 7.79	11	6	34	8				
2. 8.79	44	40	19	26				
30. 8.79	40	68	200	30				
4.10.79	60	41	63	46				
1.11.79	18	35	15	38				
3.12.79	140	31	24	17				
2. 1.80	138	245	43	70				
1. 2.80	13	32	70	57				
29. 2.80	140	54	45	50				
11. 3.80	-	-	-	-				
28. 3.80	74	86	62	49				

DUST MEASUREMENTS WITH CERL DUST GAUGES
ON THE COPPER HEAD SLIME DUMP, BULLFINCH.

GAUGE NO. 7

DATE	OBSCURATION UNITS				WEIGHT OF SAMPLES (MILLIGRAMS)			
	W	S	E	N	W	S	E	N
24.10.78								
28.11.78	80	61	42	49	30	40	40	160
19.12.78	80	75	85	130	150	170	120	380
15. 1.79	29	36	35	73	90	90	110	320
12. 2.79	50	62	105	100	120	140	200	100
13. 3.79	39	26	24	52				
11. 4.79	148	62	40	91				
10. 5.79	21	24	28	19				
7. 6.79	34	19	12	17				
5. 7.79	7	9	7	22				
2. 8.79	59	42	25	19				
30. 8.79	19	27	20	24				
4.10.79	61	33	29	65				
1.11.79	50	140	95	250				
3.12.79	130	130	-	390				
2. 1.80	109	851	79	65				
1. 2.80	67	160	110	250				
29. 2.80	8	20	55	145				
11. 3.80	-	-	-	-				
28. 3.80	64	80	73	75				

GAUGE NO. 8

DATE	OBSCURATION UNITS				WEIGHT OF SAMPLES (MILLIGRAMS)			
	W	S	E	N	W	S	E	N
24.10.78								
28.11.78	99	76	100	61	150	60	50	30
19.12.78	24	75	70	50	50	120	110	40
15. 1.79	31	23	59	49	70	130	270	130
12. 2.79	27	19	59	25	30	80	130	90
13. 3.79	32	17	23	43				
11. 4.79	135	65	86	126				
10. 5.79	24	15	19	16				
7. 6.79	29	13	46	32				
5. 7.79	25	11	17	10				
2. 8.79	-	-	-	-				
30. 8.79	50	42	80	45				
4.10.79	18	40	43	26				
1.11.79	50	12	15	20				
3.12.79	24	20	17	21				
2. 1.80	98	157	47	50				
1. 2.80	55	31	47	92				
29. 2.80	38	13	64	50				
11. 3.80	-	-	-	-				
28. 3.80	44	67	61	50				

GAUGE NO. 9

DATE	OBSCURATION UNITS				WEIGHT OF SAMPLES (MILLIGRAMS)			
	W	S	E	N	W	S	E	N
24.10.78								
28.11.78	66	80	110	130	30	30	50	60
19.12.78	70	32	90	100	60	20	80	140
15. 1.79	36	57	30	278	100	80	80	470
12. 2.79	56	30	150	135	90	100	160	130
13. 3.79	32	17	23	43				
11. 4.79	325	108	124	324				
10. 5.79	23	18	34	41				
7. 6.79	23	17	27	26				
5. 7.79	11	18	12	26				
2. 8.79	36	32	27	30				
30. 8.79	47	30	49	60				
4.10.79	25	30	35	17				
1.11.79	28	12	28	25				
3.12.79	17	21	12	58				
2. 1.80	118	179	62	117				
1. 2.80	140	65	180	250				
29. 2.80	35	41	250	37				
11. 3.80	-	-	-	-				
28. 3.80	59	65	105	63				

DUST MEASUREMENTS WITH CERL DUST GAUGES ON THE COPPER HEAD SLIME DUMP, BULLFINCH.

GAUGE NO. 10

DATE	OBSCURATION UNITS W	S	E	N	WEIGHT OF SAMPLES (MILLIGRAMS) W	S	E	N
24.10.78								
28.11.78	2200	3550	600	219	450	680	120	120
19.12.78	1800	4500	-	1000	920	4580	-	350
15. 1.79	439	237	113	105	430	380	120	140
12. 2.79	-	-	-	-				
13. 3.79	75	80	70	33				
11. 4.79	279	86	83	228				
10. 5.79	61	60	21	37				
7. 6.79	63	59	26	35				
5. 7.79	14	24	9	11				
2. 8.79	490	495	57	32				
30. 8.79	68	154	170	39				
4.10.79	2750	3250	100	95				
1.11.79	6000	6250	650	600				
3.12.79	1760	2700	145	800				
2. 1.80	8250	17800	1200	1050				
1. 2.80	99	520	690	140				
29. 2.80	250	250	350	145				
11. 3.80	-	-	-	-				
28. 3.80	1400	4250	1200	400				

GAUGE NO. 11

DATE	OBSCURATION UNITS W	S	E	N	WEIGHT OF SAMPLES (MILLIGRAMS) W	S	E	N
24.10.78								
28.11.78								
19.12.78								
15. 1.79								
12. 2.79								
28. 2.79								
13. 3.79								
23. 3.79								
11. 4.79	2 014	870	13 540	12 600	2 130	760	12 200	14 650
10. 5.79	3 369	740	485	880	4 580	670	460	1 080
7. 6.79	450	584	130	435	510	730	280	630
5. 7.79	30	19	25	32	40	30	30	30
2. 8.79	850	1 850	950	5 250	90	1 070	100	2 650
30. 8.79	565	140	335	95	490	90	500	80
4.10.79	2 050	2 950	1 000	900	420	2 510	260	240
28.10.79	500	150	2 050	750	570	230	2 470	2 800
7.11.79	950	1 800	4 750	4 500	270	250	1 830	2 170
3.12.79	6 000	3 200	10 500	6 500	-	-	-	-
21.12.79	4 725	11 200	1 645	3 450	8 930	24 900	1 870	3 220
2. 1.80	2 950	1 050	8 850	2 450	3 790	920	11 210	2 450
17. 1.80	2 550	1 150	3 850	2 050	-	1 530	7 630	3 860
1. 2.80	960	1 260	6 250	550	430	900	10 330	1 140
13. 2.80	450	650	7 000	4 000	470	750	17 650	2 370
29. 2.80	350	365	8 000	600	460	430	3 870	960
11. 3.80	900	600	200	2 550	750	680	270	1 410
28. 3.80	2 450	2 250	7 500	1 600	2 020	1 450	9 140	900

GAUGE NO. 12

DATE	OBSCURATION UNITS W	S	E	N	WEIGHT OF SAMPLES (MILLIGRAMS) W	S	E	N
24.10.78								
28.11.78								
19.12.78								
15. 1.79								
12. 2.79								
28. 2.79								
13. 3.79								
23. 3.79								
11. 4.79	-	760	12 320	742	-	4 600	11 110	-
10. 5.79	2 480	600	375	695	2 660	620	300	760
7. 6.79	440	275	78	365	490	260	60	350
5. 7.79	51	20	26	29	50	20	10	7
2. 8.79	-	-	-	-	-	-	-	-
30. 8.79	365	110	332	48	330	120	350	50
4.10.79	2 500	2 900	850	900	1 720	2 220	290	210
28.10.79	750	350	2 500	3 050	770	370	2 650	2 960
7.11.79	1 100	1 150	4 500	7 000	320	330	2 370	2 900
3.12.79	3 350	2 450	10 500	6 500	-	-	-	-
21.12.79	6 825	8 750	1 820	4 025	8 660	14 750	1 400	3 870
2. 1.80	2 700	1 050	9 200	2 450	3 110	900	11 260	2 710
17. 1.80	1 850	550	5 750	4 800	3 690	1 370	9 520	-
1. 2.80	750	850	9 000	1 450	680	950	11 850	1 380
13. 2.80	-	-	-	-	-	-	-	-
29. 2.80	-	-	-	-	-	-	-	-
11. 3.80	1 800	1 200	600	3 500	1 110	590	400	1 720
28. 3.80	2 350	1 650	12 500	1 000	2 240	1 440	11 740	640

DUST MEASUREMENTS WITH CERL DUST GUAGES ON THE COPPERHEAD SLIME DUMP, BULLFINCH.

DATE	GAUGE NUMBERS									
	1	2	3	4	5	6	7	8	9	10
1978										
28/11	443	236	165	5.1	3.3	1.7	2.4	3.5	4.0	68
19/12	615	731	275	19.6	4.4	2.9	6.3	3.8	4.8	-
1979										
15/1	292	347	262	19.5	6.6	4.8	2.3	2.2	5.6	11.9
12/2	402	147	77.3	6.0	3.5	3.1	4.1	1.7	4.9	-
28/2	102	124	56.9							
13/3	732	772	54.3	3.5	1.6	2.8	1.8	1.4	1.5	3.3
23/3	1590	542	244							
11/4	-	276	232	10.8	4.4	5.1	4.5	5.4	11.5	8.8
10/5	19.5	21.3	15.5	1.9	1.0	3.3	1.2	1.0	1.5	2.3
7/6	20.2	13.9	10.8	2.4	1.2	1.6	1.1	3.1	1.3	2.6
5/7	2.3	2.6	1.4	1.9	0.9	1.0	0.7	1.0	1.1	1.0
2/8	170	177	4.4	2.2	1.7	1.8	2.0	-	1.7	15.0
30/8	18	15	11	2.8	1.6	4.7	1.2	3.0	2.3	6.0
4/10	74	54	16.9	3.4	2.4	2.2	2.0	1.4	1.1	66.5
28/10	79	64	196	6.6	1.9	1.4	7.1	1.3	1.2	180
7/11	337	288	480							
3/12	360	203	210	11.5	1.6	2.2	-	0.8	1.1	56
21/12	442	169	133							
1980										
2/1	557	238	130	9.1	4.3	6.0	13.4	4.2	5.8	342
17/1	370	214	167							
1/2	169	132	-	5.4	3.8	2.1	7.2	2.8	7.8	17.7
13/2	202	374	-							
29/2	164	66.6	57.4	2.3	1.3	3.7	2.9	2.1	4.7	12.8

TABLES

TABLE 6

Dust Measurements with CERL Dust Gauges on Chaffers
Slime Dump

GAUGE NO. 1

Date	Obscuration Units				Weight of Sample (milligrams)			
	W	S	E	N	W	S	E	N
11. 8.76		installed						
14. 9.76	5,250	1,400	2,000	12,500	6,360	1,270	1,940	15,120
17.10.76	7,250	1,350	1,500	5,000	8,050	1,390	1,050	5,340
14.11.76	6,250	7,500	1,000	5,000	14,970	28,290	1,420	23,630
19.12.76	7,250	2,250	1,300	4,000	12,800	4,520	400	4,310
21. 1.77	15,000	6,750	3,100	15,500	19,020	8,960	4,470	24,090
21. 2.77	10,000	12,500	7,000	8,500	15,020	15,200	7,220	11,370
4. 4.77	2,000	2,250	1,800	7,250	3,080	2,530	2,020	9,930
9. 5.77	310	350	290	410	290	700	270	330
15. 6.77	2,800	450	950	8,750	2,190	40	770	8,770
20. 7.77	1,200	650	800	4,600	870	4,180	960	4,360
26. 8.77	14,350	2,750	19,750	3,600	35,600	3,480	18,370	2,400
6.10.77	3,350	2,350	1,350	3,600	2,030	1,840	1,120	1,970
29.11.77	621	2,000	2,400	2,950	2,290	2,730	-	2,500
5. 4.78	1,900	2,850	1,950	10,000	-	-	-	-

TABLE 7

Dust Measurements with CERL Dust Gauges on Chaffers
Slime Dump

GAUGE NO. 2

Date	Obscuration Units				Weight of Sample (milligrams)			
	W	S	E	N	W	S	E	N
11. 8.76		installed						
14. 9.76	3,500	1,300	1,500	2,800	4,160	810	1,580	14,260
17.10.76	4,100	1,700	4,700	4,000	7,910	1,870	10,350	7,060
14.11.76	12,500	1,950	5,750	2,650	34,180	3,730	5,590	-
19.12.76	12,500	2,750	6,000	3,750	26,380	3,600	15,110	7,890
21. 1.77	12,000	8,000	9,250	6,500	20,320	16,100	14,590	13,700
21. 2.77	5,000	13,500	14,000	5,500	7,160	35,680	24,400	8,130
4. 4.77	3,900	9,500	8,250	4,750	6,850	20,670	12,200	8,140
9..5.77	400	600	2,650	460	1,140	1,610	6,040	2,470
15. 6.77	2,400	950	2,850	1,400	2,930	590	5,550	4,010
20. 7.77	2,450	650	1,200	3,600	23,90	-	1,550	4,650
26. 8.77	19,700	2,250	850	6,700	16,760	470	1,070	3,880
6.10.77	3,950	2,800	15,100	4,000	4,670	3,270	19,380	4,540
29.11.77	5,000	3,950	-	2,480	10,880	10,150	-	-

TABLE 8

Dust Measurements with CERL Dust Gauges on Chaffer's Slime Dump

GAUGE NO. 3

Date	Obscuration Units				Weight of Sample (milligrams)			
	W	S	E	N	W	S	E	N
11. 8.76		installed						
14. 9.76	5,500	4,650	1,950	9,500	8,030	4,630	1,870	15,540
17.10.76	3,500	2,950	4,700	3,750	5,120	4,360	6,750	5,490
14.11.76	28,000	7,000	2,400	5,250	64,330	28,990	5,040	20,730
19.12.76	14,000	5,000	5,500	7,500	55,470	3,810	17,460	23,110
21. 1.77	13,500	170,000	8,250	11,000	24,580	517,890	16,970	22,430
21. 2.77	8,000	-	7,250	6,500	15,250	-	11,860	9,610
4..4.77	5,000	12,500	5,500	7,500	12,200	57,910	7,890	15,400
9. 5.77	950	5,000	2,450	1,600	2,360	13,060	4,680	6,010
15. 6.77	1,100	600	1,600	8,750	1,750	630	480	6,310
20. 7.77	5,200	750	2,050	10,750	5,180	-	1,600	17,530
26. 8.77	-	1,400	1,750	13,750	-	970	2,070	19,800
6.10.77	7,750	16,300	23,300	4,500	7,720	26,880	15,620	10,090
29.11.77	7,600	50,550	9,500	4,350	16,350	-	16,360	13,610
5. 4.78	-	12,500	10,750	9,250				

TABLE 9

Dust Measurements with CERL Dust Gauges on Chaffer's Slime Dump

GAUGE NO. 4

Date	Obscuration Units				Weight of Sample (milligrams)			
	W	S	E	N	W	S	E	N
11. 8.76		installed						
14. 9.76	8,000	4,000	1,400	2,350	8,270	5,550	1,050	1,760
17.10.76	10,500	5,000	8,500	8,000	16,080	7,370	11,900	9,670
14.11.76	7,500	3,750	2,250	3,200	19,180	8,670	3,770	1,920
19.12.76	7,500	8,250	7,250	20,000	19,240	22,270	19,750	61,670
21. 1.77	17,000	14,000	10,000	12,250	34,890	34,070	16,600	22,970
21. 2.77	10,000	15,000	8,000	8,500	22,160	35,850	17,970	12,910
4. 4.77	10,000	13,000	8,750	7,000	22,320	35,010	17,480	13,990
9. 5.77	1,500	-	6,500	5,500	6,440	-	11,750	8,910
15. 6.77	700	600	1,100	2,550	440	380	1,260	2,650
20. 7.77	142	183	211	1,100	180	-	230	650
26. 8.77	24,800	1,550	2,700	3,100	21,430	440	1,980	1,430
6.10.77	8,650	11,800	29,250	11,500	15,360	23,700	38,240	16,880
29.11.77	7,000	10,000	23,000	10,000	27,670	41,080	-	23,110
5. 4.78	22,000	23,500	18,500	20,000				

TABLE 10

Dust Measurements on CERL Dust Gauges on Chaffer's Slime Dump

GAUGE NO. 5

Date	Obscuration Units				Weight of Sample (milligrams)			
	W	S	E	N	W	S	E	N
11. 8.76		installed						
14. 9.76	19,500	109,000	6,300	5,000	23,970	170,000	7,400	5,630
17.10.76	290,000	5,750	7,500	10,500	25,330	24,890	32,230	14,760
14.11.76	8,750	7,500	1,850	12,500	20,610	17,570	3,360	18,100
19.12.76	12,500	13,500	10,000	10,000	28,570	122,240	28,000	18,380
21. 1.77	14,000	75,000	13,500	8,000	20,990	138,160	22,860	13,100
21. 2.77	3,500	18,500	5,750	4,000	3,240	36,870	7,810	3,580
4. 4.77	1,450	8,750	4,100	3,250	1,780	16,230	4,410	3,600
9. 5.77	230	900	1,500	650	130	3,100	3,100	870
15. 6.77	450	1,800	2,050	850	400	1,710	3,450	970
20. 7.77	237	1,200	2,300	169	450	1,030	-	320
26. 8.77	485	4,300	12,650	28,000	-	2,510	6,550	20,750
6.10.77	5,300	30,000	23,250	3,250	3,480	39,040	74,310	13,300
29.11.77	1,950	5,750	10,000	3,500	8,790	9,100	8,910	2,200
5. 4.78	4,000	20,500	10,000	19,250				

TABLE 11

Dust Measurements with CERL Dust Gauges on Chaffer's Slime Dump

GAUGE NO. 6

Date	Obscuration Units				Weight of Sample (milligrams)			
	W	S	E	N	W	S	E	N
11. 8.76		installed						
14. 9.76	27,000	12,200	840	6,450	29,160	14,130	730	5,660
17.10.76	16,500	4,500	3,350	4,050	24,970	10,540	4,380	4,140
14.11.76	31,500	13,000	3,500	4,750	46,010	21,690	1,470	8,380
19.12.76	18,500	7,250	1,750	7,000	21,500	11,880	3,100	8,310
21. 1.77	18,500	17,000	4,200	9,750	31,550	60,700	6,510	13,880
21. 2.77	5,750	7,500	2,150	2,000	8,190	10,800	1,850	1,750
4. 4.77	8,250	10,000	1,750	5,000	12,270	13,880	2,170	3,720
9. 5.77	330	560	440	300	340	870	480	340
15. 6.77	-	-	-	-	-	-	-	-
20. 7.77	-	-	-	-	-	-	-	-
26. 8.77	3,600	3,400	1,300	20,600	-	2,080	110	49,790
6.10.77	6,100	8,950	7,650	6,350	8,720	8,290	17,470	4,690
29.11.77	8,750	3,250	3,000	3,000	15,000	3,310	3,640	3,180
5. 4.78	16,750	5,750	12,500	8,250	-	-	-	-

TABLE 12

Dust Measurements with CERL Dust Gauges on Chaffer's Slime Dump

GAUGE NO. 7

Date	Obscuration Units				Weight of Sample (milligrams)			
	W	S	E	N	W	S	E	N
11. 8.76		installed						
14. 9.76	19,500	17,100	4,350	16,500	26,870	20,690	3,930	15,600
17.10.76	19,500	10,000	3,350	10,000	37,490	13,240	3,710	15,630
14.11.76	43,000	7,750	3,000	12,500	77,180	30,560	6,950	34,600
19.12.76	10,000	5,250	12,250	2,100	37,450	6,750	22,050	2,260
21. 1.77	25,000	17,000	8,250	9,500	55,600	35,050	13,310	30,200
21. 2.77	4,250	7,500	3,750	1,750	5,420	11,750	3,670	1,800
4. 4.77	4,400	5,500	2,250	2,450	10,000	9,040	3,440	3,320
9. 5.77	300	750	340	550	390	1,040	400	240
15. 6.77	1,500	2,350	550	4,100	3,580	670	90	1,540
20. 7.77	20,000	4,400	210	1,900	10,050	2,250	-	1,600
26. 8.77	40,250	6,450	3,200	19,750	66,120	3,010	1,420	29,500
6.10.77	8,650	5,600	9,550	3,450	10,780	7,280	8,020	2,750
29.11.77	4,250	2,100	3,450	1,600	-	2,860	4,800	3,050
5. 4.78	4,500	5,500	6,500	6,000				

TABLE 13

Dust Measurements with CERL Dust Gauges on Chaffer's Slime Dump

GAUGE NO. 8

Date	Obscuration Units				Weight of Sample (milligrams)			
	W	S	E	N	W	S	E	N
11. 8.76		installed						
14. 9.76	7,000	8,600	2,300	8,600	9,110	9,910	2,550	10,300
17.10.76	5,250	3,200	3,300	8,000	6,270	3,520	3,520	11,830
14.11.76	3,500	3,400	3,000	8,750	7,570	4,960	4,250	17,500
19.12.76	4,250	2,450	1,800	6,000	16,230	3,130	2,380	6,970
21. 1.77	7,000	13,000	7,250	10,500	10,490	13,120	9,420	16,090
21. 2.77	2,500	9,500	2,350	4,000	3,440	15,050	2,850	5,730
4. 4.77	1,750	5,500	1,950	3,100	2,210	7,280	2,570	4,600
9. 5.77	170	850	420	250	260	430	390	400
15. 6.77	-	-	-	-	-	-	-	-
20. 7.77	2,300	4,600	42	4,400	1,810	1,070	220	3,100
26. 8.77	18,750	5,350	8,500	14,250	22,500	2,740	6,430	13,700
6.10.77	3,250	3,000	3,700	5,250	1,980	1,720	2,650	4,000
29.11.77	14,500	1,000	2,000	1,600	19,200	-	6,350	140
5. 4.78	4,400	2,000	4,000	8,500				

TABLE 14

Dust Measurements with CERL Dust Gauges on Chaffer's Slime Dump

GAUGE NO. 9

Date	Obscuration Units				Weight of Sample (milligrams)			
	W	S	E	N	W	S	E	N
11. 8.76	installed							
14. 9.76	2,050	550	147	555	1,870	420	30	510
17.10.76	5,250	1,200	1,100	2,950	5,040	940	830	2,220
14.11.76	7,000	1,200	1,050	2,200	13,280	810	930	2,460
19.12.76	7,500	1,500	1,100	2,000	12,100	1,850	1,490	2,890
21. 1.77	6,500	17,750	3,650	8,500	9,310	11,710	4,800	10,410
21. 2.77	3,400	8,000	5,750	2,350	3,010	10,850	4,600	1,660
4. 4.77	850	4,250	2,350	2,400	1,070	5,210	2,330	2,870
9. 5.77	210	320	360	300	260	840	870	480
15. 6.77	550	500	350	900	290	-	50	1,170
20. 7.77	251	32	33	160	150	-	20	230
26. 8.77	12,750	2,000	1,600	3,900	14,380	620	1,200	3,210
6.10.77	2,250	1,450	4,100	2,900	620	1,290	3,110	1,340
29.11.77	1,700	2,300	2,000	1,050	1,660	3,020	4,340	1,050
5. 4.78	1,450	6,000	6,750	4,000				

TABLE 17

Percentage Direction Wind Frequencies for Kalgoorlie for August 1976 - November 1977

DATE	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N	CALM
11. 8.76																	
14. 9.76	4.2	4.2	1.9	1.9	3.4	6.4	2.3	5.3	6.1	13.3	3.0	6.8	2.6	6.1	2.6	6.4	23.5
17.10.76	7.6	6.1	9.8	13.6	9.1	8.0	3.8	2.6	3.0	6.1	1.5	7.2	2.3	1.5	0.8	3.8	13.2
14.11.76	2.2	3.1	1.3	8.5	6.3	8.0	10.7	13.8	4.9	3.1	4.9	12.9	4.0	2.7	3.1	4.5	3.8
19.12.76	3.6	6.1	4.3	9.3	7.5	12.9	7.5	6.1	6.8	8.9	2.9	6.4	2.5	2.1	1.1	6.8	7.6
21. 1.77	4.5	5.7	3.4	6.8	12.1	13.6	11.0	6.4	3.0	7.2	4.2	3.8	1.1	1.1	3.0	3.8	9.3
9. 5.77																	
15. 6.77	2.0	5.7	8.6	8.1	3.7	2.4	4.4	4.7	3.4	3.4	6.7	10.8	5.4	6.4	5.4	8.8	9.3
20. 7.77	3.2	3.6	3.2	3.9	4.3	5.4	3.2	4.6	2.5	0.7	2.8	3.6	3.9	2.8	10.0	6.8	35.5
26. 6.77	2.0	1.4	1.4	1.0	1.0	1.0	2.4	0.3	2.0	4.4	8.1	13.2	5.4	7.8	4.4	3.7	40.5
6.10.77	2.1	3.7	2.4	6.7	7.6	9.4	7.0	5.8	4.3	1.8	4.0	5.2	5.2	1.8	1.8	2.4	28.8
29.11.77	1.8	3.7	5.8	11.1	9.3	4.4	8.1	6.5	2.8	3.9	5.6	5.1	2.5	2.8	0.9	3.0	22.7

TABLE 18

CERL GAUGE NO. 2 — SOUTH POT FACING INWARDS TO SLIME DUMP

	OBSCURATION	WEIGHT OF DUST (mg)	PER CENT.OF TIME WIND	CORRECTED RESULTS AS IF WIND BLEW IN THAT DIRECTION ALL THE TIME		AVERAGE WIND SPEED (knots)	RAIN DURING PERIOD (mm)	LONGEST PERIOD WITHOUT RAIN (days)
				Obscuration	Weight (milligrams)			
11.08.76	Before treatment							
14.09.76	1 300	810	33.4	3 890	2 420	6.7	98	14) *
17.10.76	1 700	1 870	23.5	7 230	7 960	7.5	354	14)
14.11.76	1 950	3 730	40.5	4 810	9 200	8.2	200	10
19.12.76	2 750	3 600	32.2	8 540	11 180	7.4	74	31) **
21.01.77	8 000	16 100	41.2	19 420	39 080	8.4	44	22)
09.05.77	After treatment							
15.06.77	950	590	18.3	5 200	3 220	4.5	378	16
20.07.77	650	-	16.4	4 000	-	5.8	50	15
26.08.77	2 250	470	10.1	22 280	4 650	5.5	106	17
06.10.77	2 800	3 270	28.3	9 900	11 550	7.3	114	19
29.11.77	3 750	10 150	25.7	14 600	39 500	7.9	296	11

* longest period of 24 days overlapping sampling date
** " " " 42 " " " "

TABLE 19

CERL GAUGE NO. 6 — NORTH POT FACING INWARDS TO SLIME DUMP

	OBSCURATION	WEIGHT OF DUST (mg)	PER CENT.OF TIME WIND	CORRECTED RESULTS AS IF WIND BLEW IN THAT DIRECTION ALL THE TIME		AVERAGE WIND SPEED (knots)	RAIN DURING PERIOD (mm)	LONGEST PERIOD WITHOUT RAIN (days)
			NW-NE	Obscuration	Weight (milligrams)			
11.08.76	Before treatment							
14.09.76	6 450	5 660	23.5	27 450	24 100	8.0	98	14)
17.10.76	4 050	4 140	19.8	20 450	20 900	7.9	354	14) *
14.11.76	4 750	8 380	15.6	30 450	53 700	9.5	200	10
19.12.76	7 000	8 310	19.7	35 530	42 200	8.7	74	31)
21.01.77	9 750	13 850	18.1	53 870	76 500	7.6	44	22 **
20.07.77	After treatment						50	15
26.08.77	20 600	49 790	19.3	106 750	258 000	8.7#	106	17
06.10.77	6 350	4 690	11.8	53 800	39 750	9.2	114	19
29.11.77	3 000	3 180	12.2	24 600	26 100	10.0	296	11

* longest period of 24 days overlapping sampling date
** " " " 42 " " " "
\# peak gust of 25 knots and period included 9 hours when wind 20 knots on 10 August 1977

TABLE 20

CERL GAUGE NO. 8 — EAST POT FACING INWARDS TO SLIME DUMP

	OBSCURATION	WEIGHT OF DUST (mg)	PER CENT.OF TIME WIND	CORRECTED RESULTS AS IF WIND BLEW IN THAT DIRECTION ALL THE TIME		AVERAGE WIND SPEED (knots)	RAIN DURING PERIOD (mm)	LONGEST PERIOD WITHOUT RAIN (days)
				Obscuration	Weight (milligrams)			
11.08.76	Before treatment							
14.09.76	2 300	2 550	17.8	12 900	14 300	4.1	98	14)
17.10.76	3 300	3 520	46.6	7 080	7 550	7.3	354	14) *
14.11.76	3 000	4 250	27.2	11 000	15 600	6.7	200	10
19.12.76	1 800	2 380	40.1	4 490	5 930	6.1	74	31)
21.01.77	7 250	9 420	41.6	17 400	22 600	7.7	44	22) **
15.06.77	After treatment						378	16
20.07.77	42	220	20.4	200	1 080	5.0	50	15
26.08.77	8 500	6 430	5.8	146 000	110 800	4.3	106	17
06.10.77	3 900	2 650	29.8	13 100	8 890	8.1	114	19
29.11.77	2 000	6 350	34.3	5 830	18 500	7.4	296	11

* longest period of 24 days overlapping sampling date
** " " " 42 " " " "

TABLE 24: <u>SAMPLING PERIODS FOR THE SALTATION AND CERL DUST GAUGES ON CHAFFERS WEST DUMP</u>

SALTATION COLLECTION PERIOD	CERL GAUGE COLLECTION DATES
	11.8.76 (installed)
	14.9.76
27.9.76 - 8.10.76	
	17.10.76
8.10.76 - 14.11.76	14.11.76
14.11.76 - 27.11.76	
27.11.76 - 19.12.76	19.12.76
19.12.76 - 8.1.76	
No Sample	21.1.77
5.2.77 - 16.2.77	
	21.2.77
16.2.77 - 22.2.77	
22.2.77 - 25.2.77	
25.2.77 - 5.3.77	
↑	4.4.77
	9.5.77
No Samples	15.6.77
	20.7.77
↓	26.8.77
15.9.77 - 26.9.77	
No Samples	6.10.77
	19.11.77
15.11.77 - 11.12.77	
11.12.77 - 23.1.78	
23.1.78 - 10.3.78	5.4.78
10.3.78 - 27.4.78	

TABLE 25

CERL DUST GAUGE RESULTS IN MILLIGRAMS FOR THE PERIOD 8 NOVEMBER 1978 - 24 JANUARY 1979

	8.11.78 - 24.11.78				24.11.78 - 6.12.78				6.12.78 - 20.12.78				20.12.78 - 24.1.79			
Gauge	W	S	E	N	W	S	E	N	W	S	E	N	W	S	E	N
1	490	120	250	490	5520	480	290	3930	840	510	1820	2310	1750	3750	3000	1170
2	1330	2000	10710	2700	20170	2870	4750	-	2300	5260	30840	4770	21350	31450	46160	11540
3	2360	26490	4110	2450	27750	33550	3160	11680	6130	123030	13110	6990	25060	298720	1080	32540
4	10940	18000	28170	13240	31980	30440	5920	12830	25390	53000	57410	23790	31000	45350	94190	51660
5	170	400	1520	30	3440	6410	890	4740	360	5460	4070	740	2310	7940	5270	1120
6	640	600	290	230	6120	1370	160	2900	1190	2590	2270	410	3270	7840	2820	740
7	1090	880	460	60	19910	5090	1240	7600	770	1220	870	490	7250	6720	1900	1740
8	210	840	150	100	3680	3880	2360	6200	180	2200	1380	1000	2860	30580	5240	1300
9	150	110	910	230	5240	890	550	9630	270	1810	4340	860	2750	8090	4260	1430

TABLE 26 CERL DUST GAUGE RESULTS IN UNITS OF OBSCURATION FOR THE PERIOD 8 NOV 1978 - 24 JAN 1979

	8.11.78 - 24.11.78				24.11.78 - 6.12.78				6.12.78 - 20.12.78				20.12.78 - 24.1.79			
Gauge	W	S	E	N	W	S	E	N	W	S	E	N	W	S	E	N
1	1200	900	700	1100	8000	1100	1150	4750	4000	1200	1300	3300	700	1550	2250	3000
2	1900	1450	10000	1600	10000	2500	3500	6000	4500	5250	7500	1650	5000	2500	7500	1000
3	1850	8000	2250	1850	12500	18500	3250	5000	2450	31250	3600	3750	7000	00	8000	4750
4	5500	6750	3000	550	12500	8500	4000	9000	5000	8250	7250	7500	8000	18500	11000	15250
5	650	750	1550	500	3250	5250	1450	4200	1200	4750	4000	2500	1250	7500	5750	4000
6	1250	1000	950	600	6500	1600	950	2550	2400	2400	2750	1600	1200	8750	1000	850
7	950	950	2100	550	15000	5250	1750	7500	1550	1950	1700	2050	3750	6000	1600	1950
8	800	1450	700	850	4500	2550	2500	2400	1100	3450	6750	2200	1100	10000	1200	1000
9	550	650	1100	650	4250	1200	900	14000	1050	3100	2800	1550	1050	5500	1450	1900

TABLE 27

Measurement of 100 (40 mm) rock fragments dropped at random

No.	Height (mm)	Area of Influence (mm^2)	No.	Height (mm)	Area of Influence (mm^2)	No.	Height (mm)	Area of Influence (mm^2)	No.	Height (mm)	Area of Influence (mm^2)
1	28.1	6591	26	44.0	16157	51	33.3	9261	76	11.7	1144
2	33.7	9475	27	39.1	12776	52	15.1	1902	77	20.0	3339
3	44.0	16162	28	15.0	1882	53	29.7	7362	76	15.0	1882
4	31.1	8075	29	19.9	3302	54	43.7	15935	79	24.9	5177
5	28.8	6911	30	35.3	10395	55	28.5	6787	80	19.7	3239
6	22.9	4386	31	31.2	8133	56	29.2	7118	81	15.3	1951
7	37.1	11495	32	32.5	8822	57	17.1	2443	82	31.2	8133
8	32.0	8548	33	24.4	4974	58	21.0	3678	83	21.1	3717
9	30.1	7569	34	23.0	4417	59	14.5	1753	84	28.6	6826
10	26.2	5730	35	23.3	4057	60	15.1	1902	85	26.5	5863
11	24.3	4928	36	18.0	2701	61	37.2	11545	86	34.4	9884
12	20.2	3404	37	19.9	3302	62	30.2	7610	87	26.2	5730
13	19.9	3302	38	40.2	13485	63	28.7	6879	88	22.1	4075
14	17.5	2554	39	29.1	7064	64	31.1	8075	89	37.2	11545
15	22.9	4375	40	19.0	3017	65	22.0	4045	90	24.0	4806
16	31.8	8436	41	34.0	9647	66	32.9	9031	91	36.5	11123
17	34.9	10170	42	24.8	5131	67	27.3	6222	92	18.0	2701
18	21.0	3678	43	20.7	3573	68	31.0	8018	93	33.0	9093
19	36.0	10823	44	34.1	9710	69	34.4	9884	94	34.2	9756
20	26.2	5730	45	26.2	5730	70	11.8	1160	95	26.0	5646
21	19.8	3275	46	33.1	9154	71	16.9	2380	96	35.0	10217
22	11.2	1050	47	33.8	9538	72	17.3	2499	97	16.1	2160
23	29.3	7173	48	20.0	3339	73	27.6	6361	98	19.1	3042
24	22.1	4075	49	17.9	2677	74	25.5	5433	99	24.2	4883
25	25.0	5224	50	20.1	3376	75	34.0	9647	100	29.3	7173

Average Height = 26.4 mm
Average Area of Influence = 58.14 cm^2
Total weight of 100 fragments = 7.239 kg
Average weight of each fragment = 0.0724 kg.

TABLE 28 CALCULATIONS OF TREATMENT RATE AND COST USING THE AVERAGE AREA OF INFLUENCE OF 40 mm ROCK FRAGMENTS

Treatment Rate Calculation

1. Average rock area of influence = 5814 mm^2
2. Average rock weight = 0.0724 Kg

No of rocks required to totally influence 1 ha

$$\frac{10 \times 10^7}{58.14} = 1719986$$

$$1719986 \times 0.0000724 = \text{tonnes/ha}$$

= approximately 124 tonnes/ha

Estimated Cost

At a suggested application rate of 125 tonnes/ha, projected treatment costs/ha using cost data from the Chaffer's South treatment, appears thus:

	$/ha
125 tonnes 40 mm rock fragments @ $7.80/tonne	975
Surveying (contours & sketch plan)	15
Ramp and approach construction	30
Dump surface preparation	80
Contour construction	10
Total:	1110
+ 10% inflation since Jan 1978	110
	$ 1221

NOTE: This estimate does not include the actual cost (machine and operator time) of laying the rock fragments.

FIGURES 1 - 9

Fig. I

DUST MONITORING
KALGOORLIE - BOULDER
April 73 - January 77

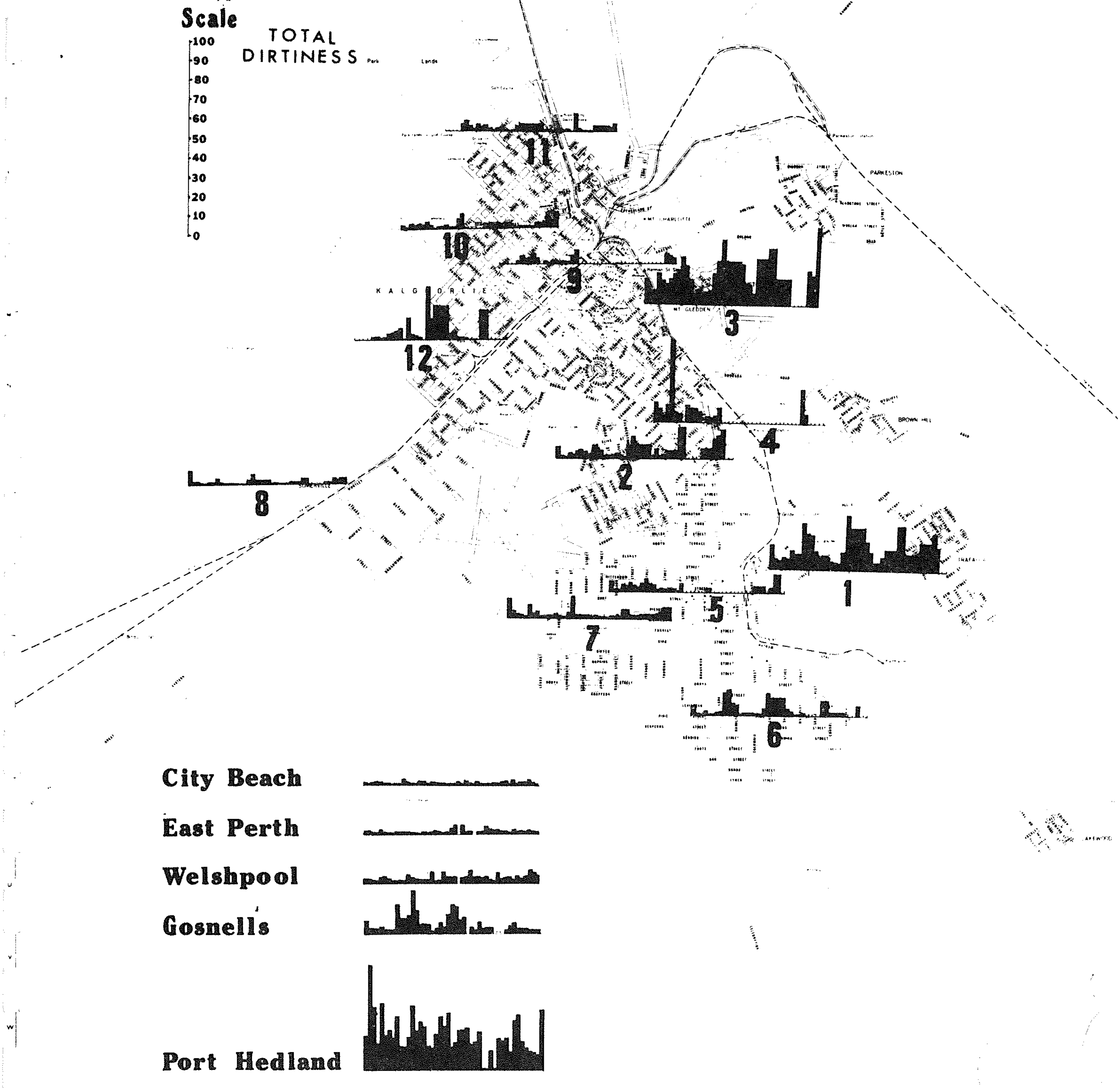


Fig. 2 COMPARISON OF AVERAGE SUMMER AND WINTER DUST LEVELS

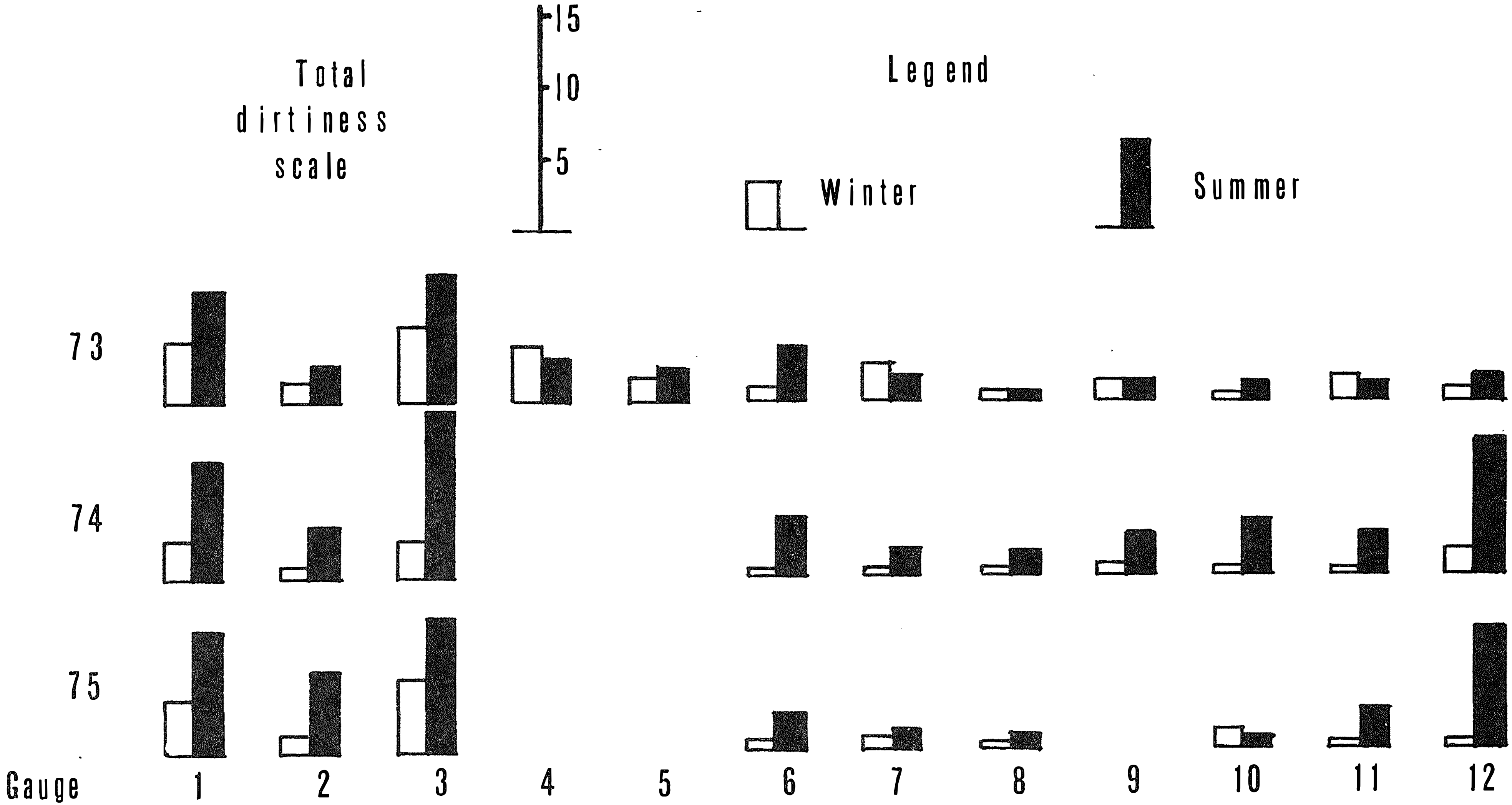


Fig. 3

DUST MONITORING

KALGOORLIE - BOULDER

March 79 - February 80

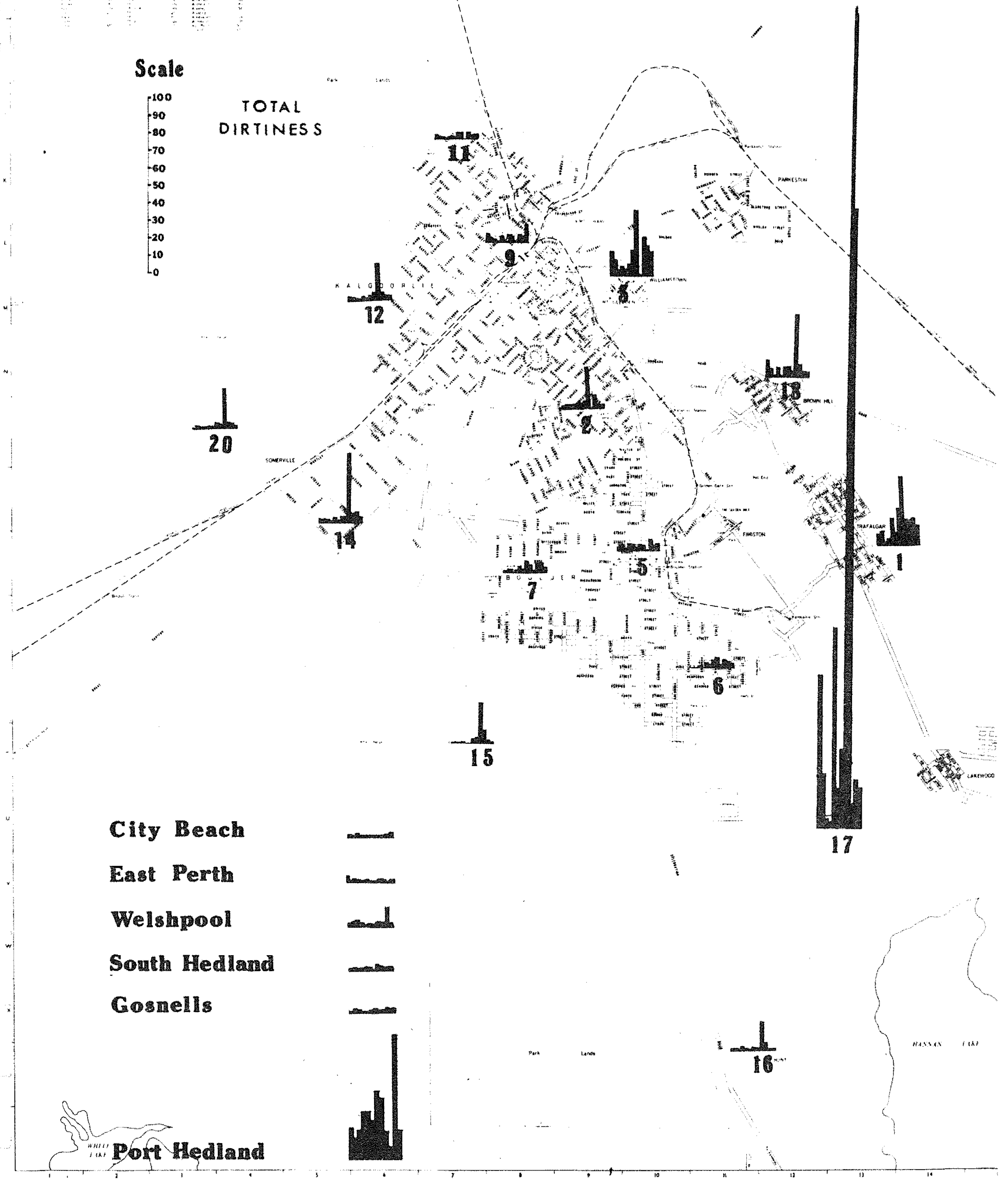


FIG.4. PRE-TREATMENT AND POST-TREATMENT DUST OBSCURATION RESULTS FROM CHAFFERS WEST.

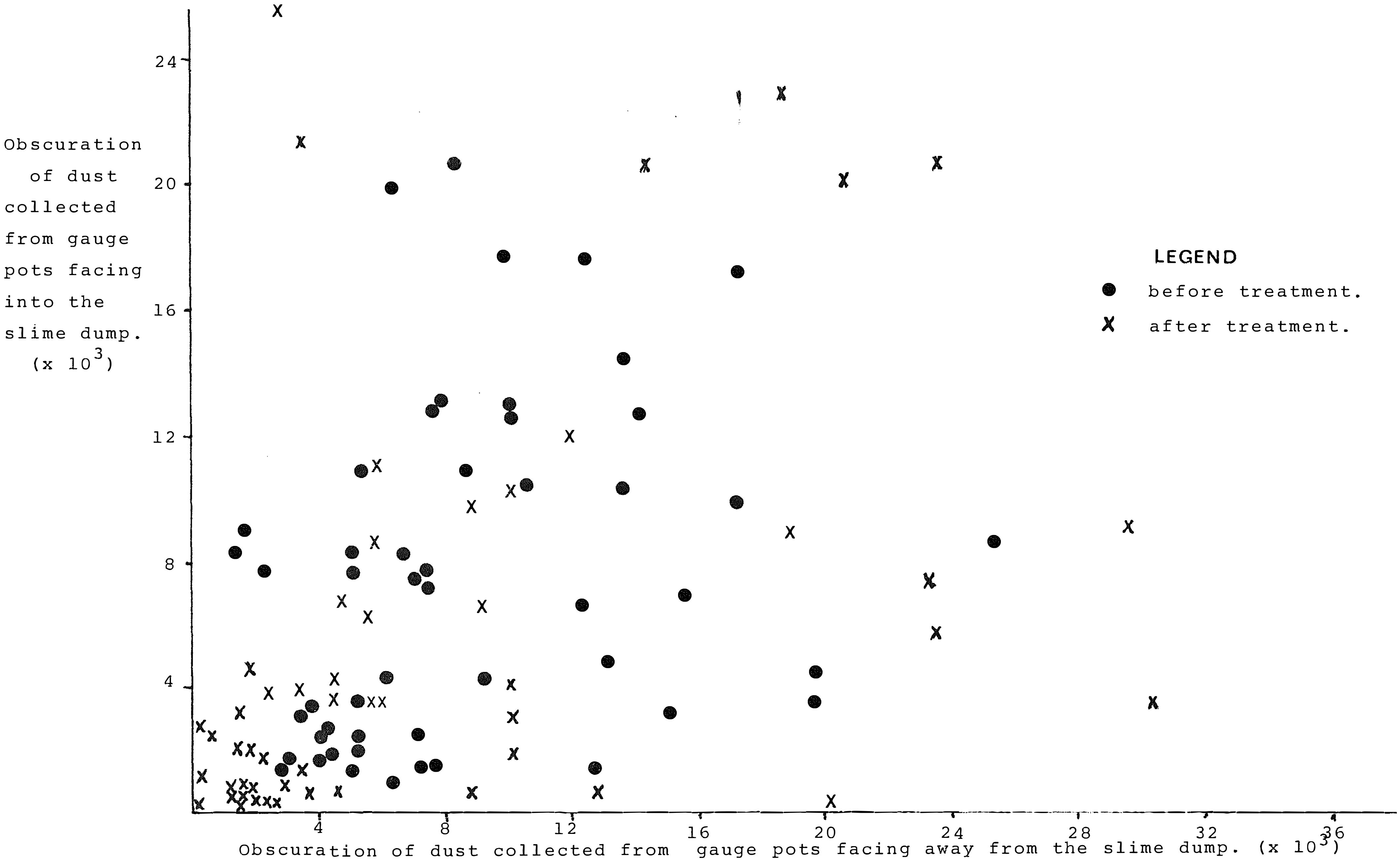
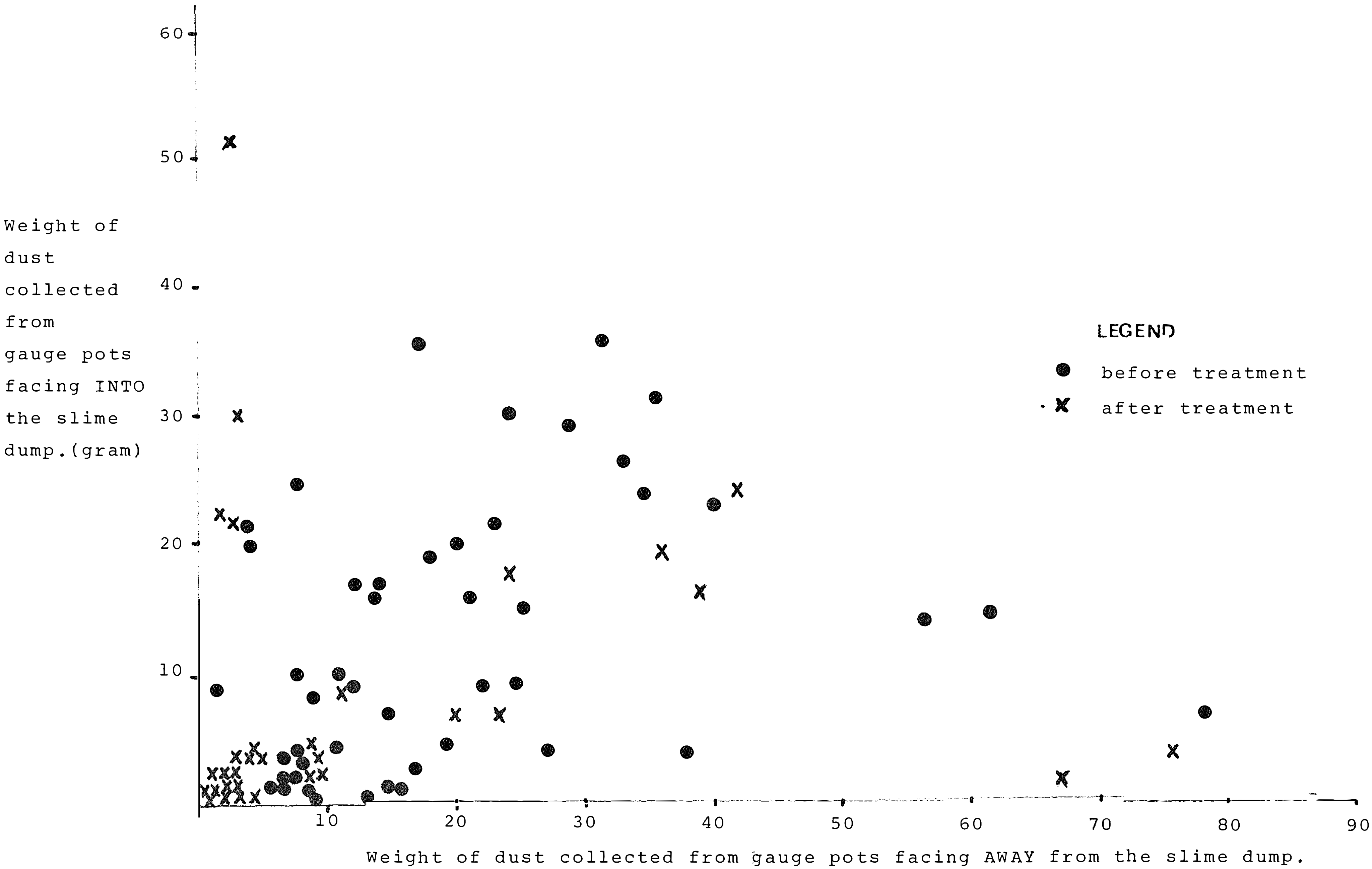


FIG.5 PRE-TREATMENT AND POST-TREATMENT DUST WEIGHT RESULTS FROM CHAFFERS WEST.



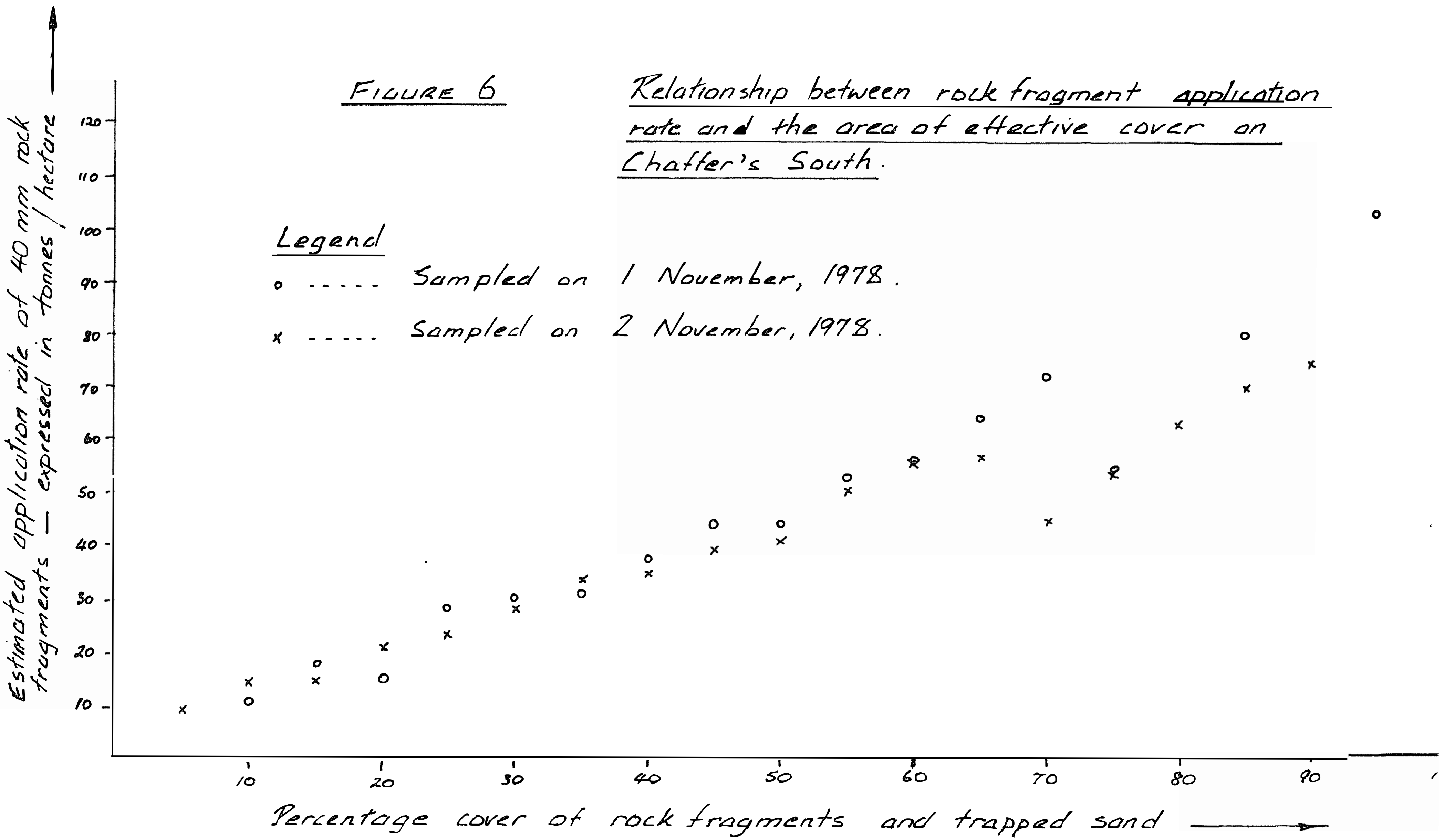
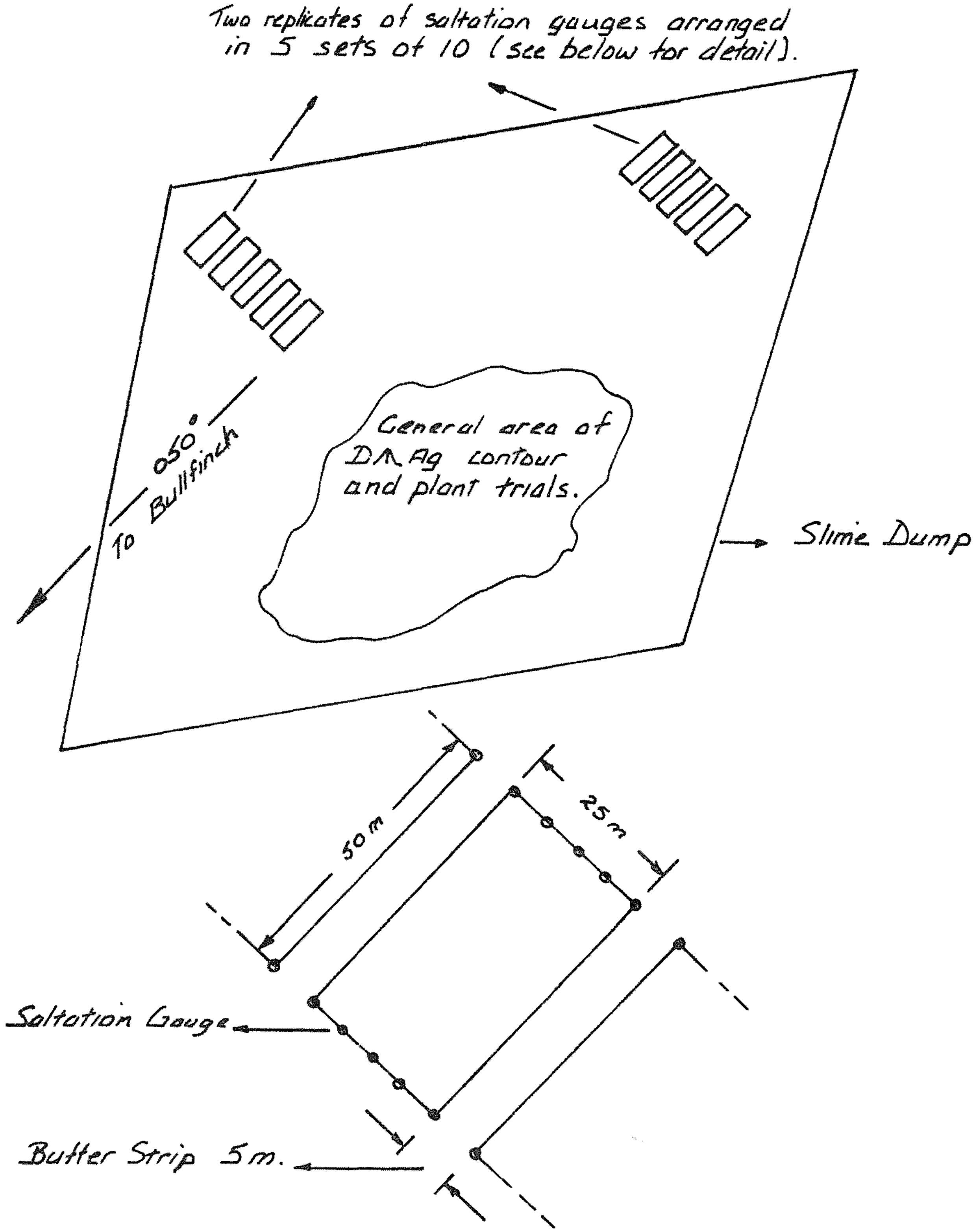


FIGURE 6
Relationship between rock fragment application rate and the area of effective cover on Chaffer's South.
Legend
o ----- Sampled on 1 November, 1978.
x ----- Sampled on 2 November, 1978.
Estimated application rate of 40 mm rock fragments — expressed in tonnes / hectare
10
20
30
40
50
60
70
80
90
100
110
120
Percentage cover of rock fragments and trapped sand
10
20
30
40
50
60
70
80
90

FIG 7. Trial Areas on the Copperhead Slime Dump – Bullfinch



BULLFINCH

Fig. 8

DUST GAUGE RESULTS
NOV 78 - FEB 80

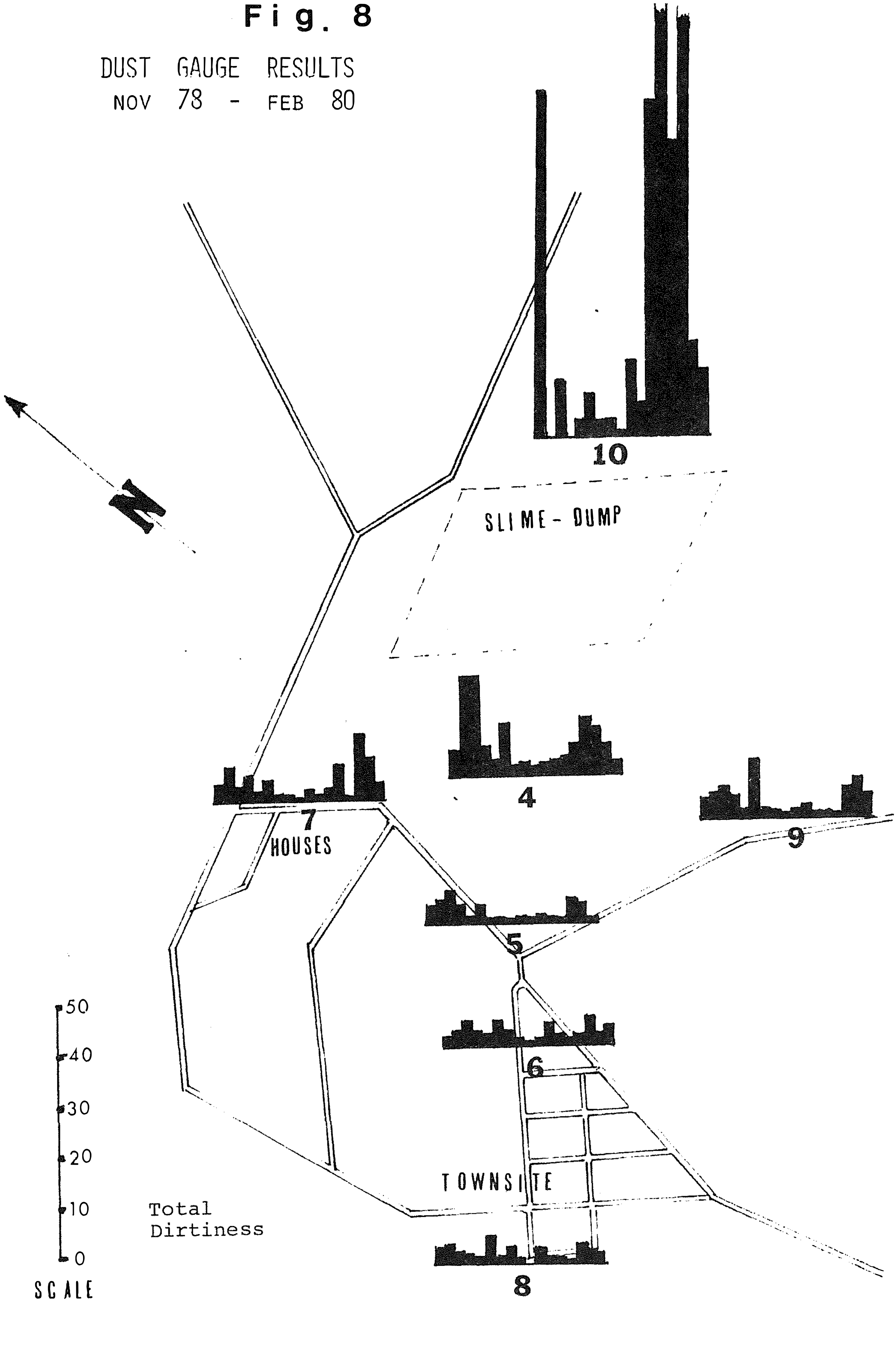
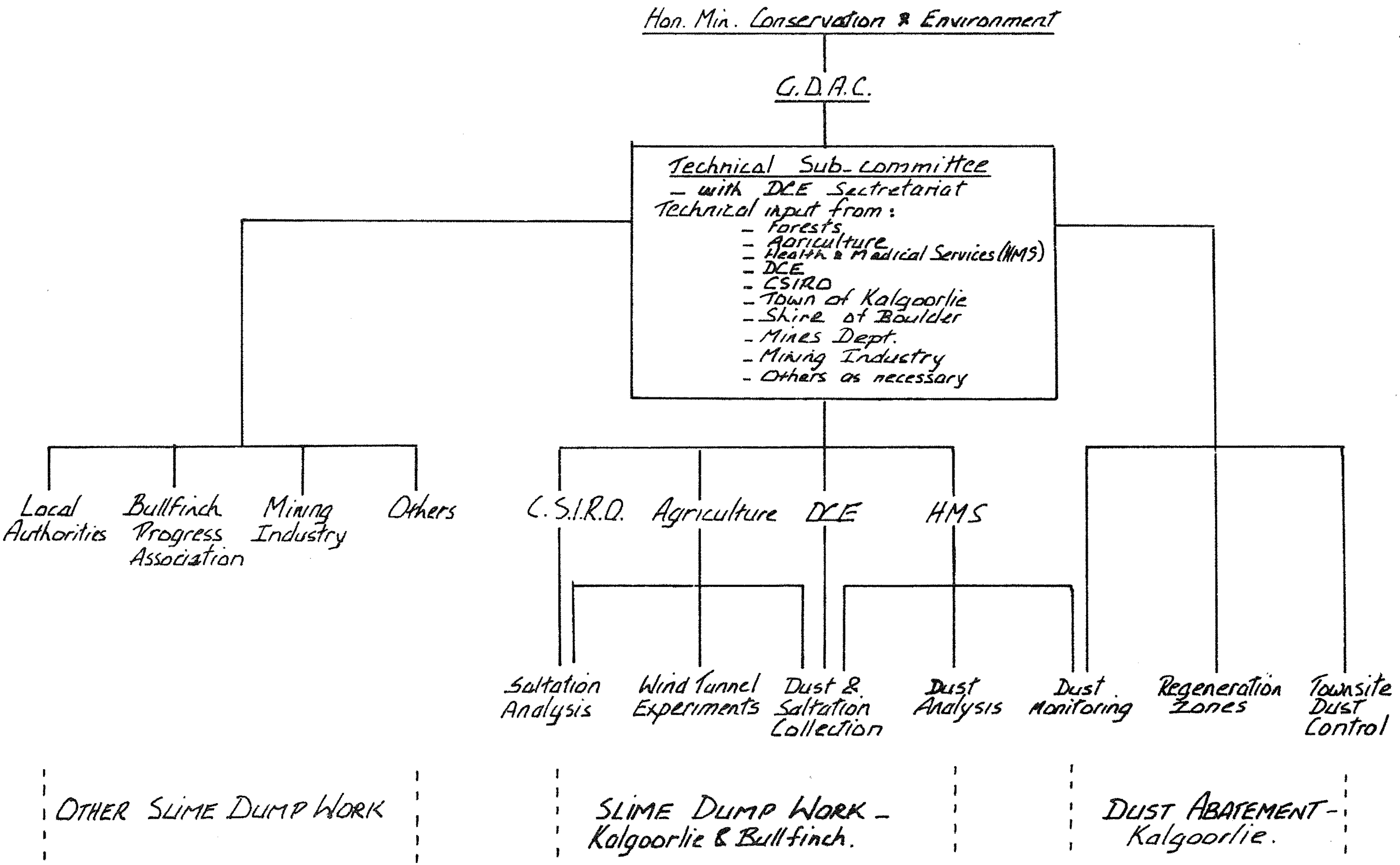
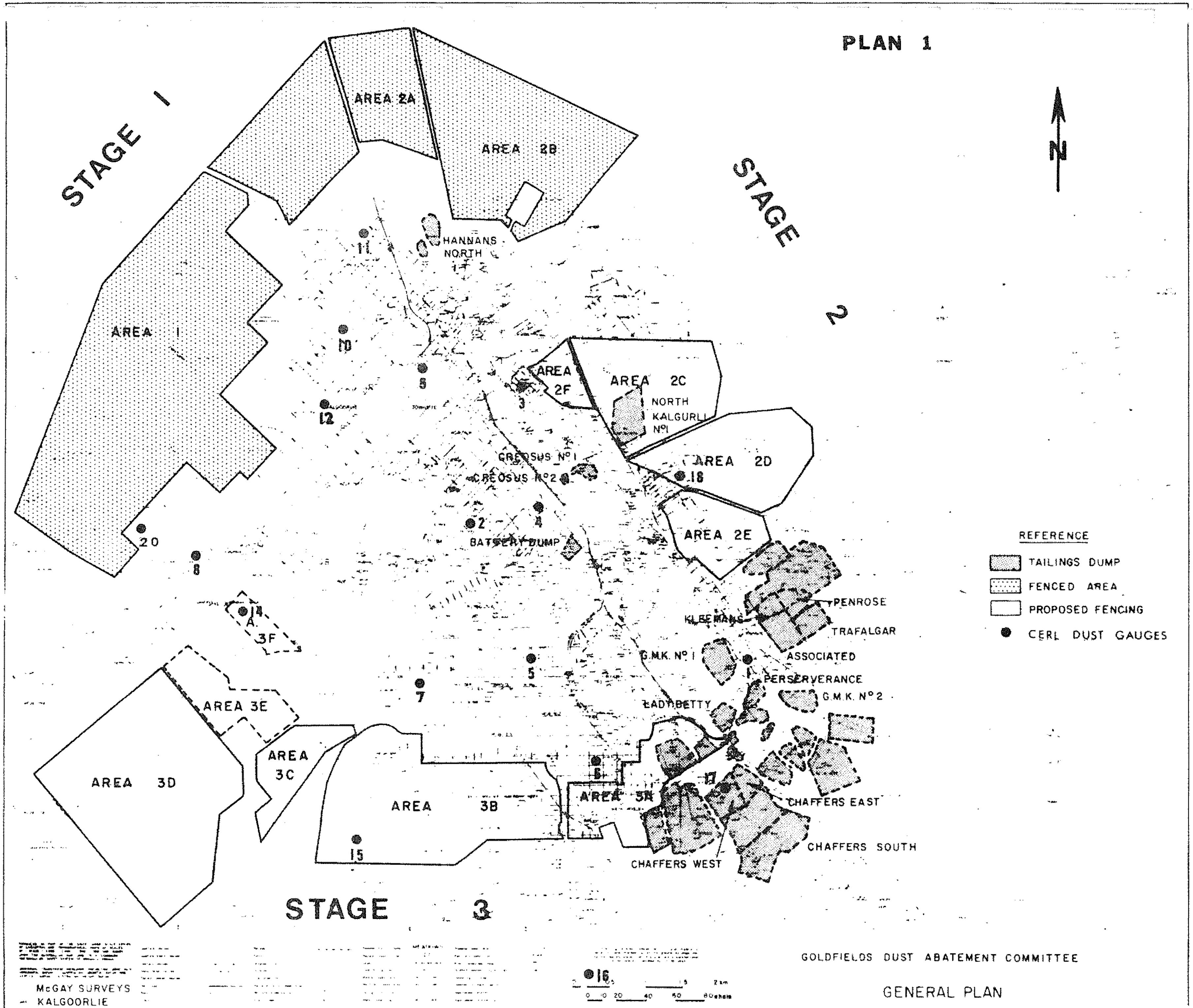


FIG 9. RESEARCH COORDINATION



PLANS 1 AND 2

PLAN 1



McGAY SURVEYS
KALGOORLIE

GOLDFIELDS DUST ABATEMENT COMMITTEE

GENERAL PLAN

BULLFINCH

PLAN 2

SITES OF CERL DUST GAUGES AND ANEMOMETER AROUND THE TOWNSITE AND SLIME-DUMP