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# DUST CONTROL ON ACTIVE TAILINGS PONDS

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## FOREWORD

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TABLE OF CONTENTS

	Page
1.0 Executive Summary .....	8
2.0 Introduction .....	10
2.1 Program Objective .....	10
2.2 Identification of Major Program Tasks .....	10
3.0 Conduct State Of The Art Survey .....	11
3.1 Information Search .....	11
3.1.1 Literature Search .....	11
3.1.2 Chemical Stabilizers .....	11
3.1.3 Application Equipment .....	12
3.2 Site Surveys .....	13
3.3 Laboratory Screening Procedures .....	14
3.4 Field Test Plan .....	14
3.4.1 Evaluation Criteria .....	14
3.4.2 Field Testing Methodology .....	15
4.0 Field Testing .....	17
4.1 Preparation .....	17
4.1.1 Site Selection .....	17
4.1.2 Test Plot Location & Size .....	17
4.1.3 Chemical Stabilizers Selected .....	19
4.2 Application Of Chemical Stabilizers .....	19
4.3 Field Sampling Procedures .....	21
4.3.1 Equipment .....	21
4.3.2 Wind Tunnel Testing Procedure .....	25
4.3.3 Silt/Moisture Sample Collection .....	29
5.0 Comparative Evaluation Of Chemical Stabilizers ..	33
5.1 Dust Control Effectiveness .....	33
5.1.1 Wind Erosion Threshold Velocities .....	33
5.1.2 Wind Erosion Emission Factors .....	54
5.2 Meteorology .....	54
5.2.1 Test Period Meteorological Conditions .	56
5.2.2 The Effect Of Meteorological Parameters On Dust Control Effectiveness .....	60
5.3 Tailings Characteristics .....	65
5.4 Chemical Stabilizer Product Usage .....	71
5.4.1 Delivery Requirements .....	71
5.4.2 Product Storage Requirements .....	73
5.4.3 Product Application Requirements .....	73
5.5 Cost Of Chemical Stabilizers .....	75
5.5.1 Product Costs .....	75
5.5.2 Labor And Equipment Costs .....	76
5.6 Control Cost Effectiveness Evaluation .....	78

	Page
6.0 Criteria For Selecting Chemical Stabilizers .....	81
6.1 Tailings Characteristics .....	81
6.2 Meteorological Conditions .....	82
6.3 Recovery Problems .....	83
6.4 Product Usage Requirements .....	83
6.5 Control Efficiency .....	83
6.6 Cost Effectiveness .....	84
7.0 Conclusions .....	85
8.0 Recommendations .....	87
9.0 References .....	89

#### APPENDICES

Appendix A: Bibliography .....	90
Appendix B: Dust Control Chemicals .....	100
Appendix C: Application Equipment .....	102
Appendix D: Company Dust Control Programs Surveyed ..	104
Appendix E: Threshold Velocity Per Test Period .....	106
Appendix F: Threshold Velocity Per Chemical Stabilizer	113
Appendix G: Effect Of Rainfall On Threshold Velocity ..	118
Appendix H: Silt Content Versus Threshold Velocity ..	123

#### LIST OF TABLES

1. Identification of Tasks .....	10
2. Evaluation Criteria .....	15
3. Chemical Stabilizers Evaluated For Effectiveness.	19
4. Chemical Stabilizer Application Data .....	20
5. Control Efficiency By Threshold Velocity .....	52
6. Control Efficiency After Two & Four Months .....	53
7. Emission Factor Testing Results .....	55
8. Daily Rainfall Greater Than 0.01 & 0.1 Inches ...	57
9. Monthly Rainfall Amounts .....	57
10. Summary Of Test Period Meteorology .....	58
11. Tailings Silt/Moisture Analysis .....	66
12. Tailings Silt/Moisture Analysis By Chemical .....	68
13. Chemical Stabilizer Application Considerations ..	74
14. Chemical Stabilizer Cost Data .....	76
15. Total Application Costs .....	77
16. Chemical Stabilizer Cost Effectiveness .....	79
17. Ranking Of Chemical Stabilizer Cost Effectiveness	80
18. Chemical Stabilizer Cost Effectiveness Summary ..	86

LIST OF FIGURES

	Page
1. Test Plot Location & Size .....	18
2. Application Vehicle Photograph .....	22
3. Test Plot Photograph .....	23
4. ES&T Field Wind Tunnel .....	24
5. ES&T Wind Tunnel Photograph .....	26
6. Cascade Impactor Photograph .....	27
7. Wind Tunnel Velocity Profile .....	28
8. ES&T Wind Tunnel Field Operation Photograph ....	30
9. Initial Test Plot Silt Content Data .....	31
10-15 Threshold Velocity Per Test Period .....	34-39
16-19 Threshold Velocity Per Chemical Stabilizer .....	41-44
20-21 Percent Of Magnesium Chloride Test Plots-Wet ...	45-46
22. Summary Of Magnesium Chloride Test Plots .....	47
23-26 Control Efficiency Over Time .....	48-51
27. Rainfall Summary .....	59
28-31 Rainfall Effect On Threshold Velocity .....	61-64
32. Test Run/Sample Locations .....	70
33. Relationship: Silt Content To Threshold Velocity	72



## 1.0 EXECUTIVE SUMMARY

The purpose of this study was to evaluate the state of the art in chemically stabilizing active tailings ponds. From this evaluation, criteria were developed and tested under field conditions to aid the manager of a tailings basin to select the best chemicals for stabilizing the surfaces of active tailings ponds.

Industrial generated tailings are a by-product of many different mining and milling industries. They include the taconite, copper, lead-zinc, and uranium industries. Many hundreds of acres of exposed fine tailings can be identified at many of these industrial plants. During periods of high wind velocities, these tailings are capable of blowing and drifting, similiar to sand in the desert. The resulting wind generated dust emissions can cause short term particulate matter air quality violations, impair visibility, and physically drift the tailings onto adjacent land areas.

Over one billion tons of tailings are produced annually in the United States. The tailings, the unwanted waste material from the ore separation process, are usually discarded into water ponds. The majority of the tailings are kept under water or kept moist to mitigate wind erosion. Tailings placed in water ponds are said to be in active storage. When the pond becomes full of tailings or the water level is lowered, the tailings dry rapidly and are quite susceptible to wind erosion.

Normally, the primary area of concern for dust control purposes in a tailings pond are the beach areas. This area is characterized by the exposed tailings stretching from the spigot or discharge point to the water of the pond. The length of this area can range from a few feet to hundreds of feet.

Tailings when discharged onto the beach areas tend to deposit in a size segregated manner. The coarser, heavier tailings settle near the discharge point while the finer tailings settle further from this point. The beach area can have a wide range of tailings particle sizes exposed on the surface. The fine particles termed silt, are ideally suitable for suspension during periods of high winds. The coarser particles aid the wind erosion process by saltating or bumping along the tailings surface during periods of high winds, dislodging fine particles into suspension.

The research in this study was divided into two major phases: (a) conducting the state of the art survey in tailings dust control, and (b) developing and field testing criteria which can be used to select chemical stabilizers.

The first phase of the study consisted of acquiring information concerning tailings dust control. Information was gathered from a search of the published literature, contact with vendors of chemical stabilizers, and contact with vendors of equipment necessary to apply the chemical stabilizers. Additionally, a number of mining



companies were surveyed to gather information concerning their experience with tailings dust control measures. It was found that few companies have had dust control programs for more than five years. There is considerable experimentation being performed by these companies to establish their dust control programs. Many of these experimental programs lead to inconclusive results because the means of testing the effectiveness over time of the applied chemical stabilizers is not being properly performed.

The final phase of the study consisted of developing a set of criteria which could be used by the manager of a tailings basin to evaluate the effectiveness of a dust control program. The general evaluation criteria developed included: (a) Dust Control Effectiveness, (b) Meteorology, (c) Tailings Characteristics, (d) Toxicity Of The Chemical Stabilizer, (e) Laboratory Testing, (f) Costs ASSOCIATED With Using The Chemical Stabilizer, (g) Product Usage Requirements, and (h) Product Cost Effectiveness.

After the selection criteria were established, a field test program was performed to gather information on four representative chemical stabilizers and evaluate them according to the established criteria. The four types of chemical stabilizers selected for the field work consisted of a petroleum resin, lignosulfonate, latex, and a salt based product.

In order to determine the control effectiveness over time of the applied chemical stabilizers, an in-situ portable field wind tunnel was utilized. The wind tunnel has an open-bottom working section which sets over the exposed tailings. Wind speeds up to 80 mph can be simulated over the tailings surface to create erosion. The wind tunnel was used to determine the threshold velocity (the wind speed where erosion begins) over time as well as particle emission factors at various wind velocities. A cascade impactor with an isokinetic sampling probe, utilizing a procedure similiar to standard industrial stack testing, was used for emission factor determination. From this information, control efficiencies over time of the four field tested chemical stabilizers were determined.

After determination of control effectiveness, the cost effectiveness of the applied chemical stabilizers was determined. Cost effectiveness is defined as the dollars expended per acre for dust control necessary to achieve a desired level of control over a typical wind erosion season. The lower the cost effectiveness value, the more efficient a product is in reducing wind erosion dust emissions. Based on the field testing performed in this study in the Iron Range of northern Minnesota, the general order of cost effectiveness from most to least was: lignosulfonate, latex, petroleum resin, and the salt. It was estimated that had the testing been performed in the western United States, under the same conditions affecting the longevity of the chemical stabilizers, the general order of cost effectiveness would have been: latex, lignosulfonate, petroleum resin, and salt.

## 2.0 INTRODUCTION

This section introduces the program objective and the various tasks undertaken to meet this objective.

### 2.1 Program Objective

-----

The overall objective of this study was to determine the state of the art in chemically stabilizing the beach areas of active tailings ponds in the United States. From the acquired information, criteria were developed and field tested to enable the manager of a tailings basin to select the best chemical(s) for stabilizing the surfaces of the tailings beach areas.

### 2.2 Identification Of Major Program Tasks

-----

In order to meet the program objectives discussed in Section 2.1, the study was divided into two major phases. The objective of Phase I was to conduct the state of the art survey concerning the chemical stabilization of tailings. The objective of Phase II was to acquire and field test the effectiveness of a number of stabilization products. The tasks required to meet the objectives of the two phases are identified in Table 1.

-----

Table 1. Identification Of Major Tasks

Phase I - Conduct State Of The Art Survey

- Task 1: Information Search
- Task 2: Site Surveys
- Task 3: Laboratory Screening Procedures
- Task 4: Prepare Field Test Plan

Phase II - Field Testing

- Task 1: Site Survey
  - Task 2: Acquire and Apply Chemical Stabilizers
  - Task 3: Field Testing, Periods 1-9
-

## 3.0 CONDUCT STATE OF THE ART SURVEY

### 3.1 Information Search

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The search for information concerning the chemical stabilization of tailings included a literature search, contact with vendors of chemical stabilizers, contact with vendors of specialized application equipment, and contact with plants which have experience in using chemical stabilizers.

#### 3.1.1 Literature Search

The literature search consisted of reviewing inhouse files on chemical dust control programs, reviewing information gathered by the Bureau Of Mines on the subject and performing a computerized literature search.

Eight major topic areas and over 75 papers were identified from the literature search. A bibliography of the items identified in the search is presented in Appendix A. The Lockheed Dialogue Information System, with access to over 100 literature files, was utilized for the computerized search.

#### 3.1.2 Chemical Stabilizers

Seven major categories of dust control chemicals were identified as having potential for the control of wind erosion dust emissions from tailings ponds. These major categories of chemical stabilizers include: (a) Fabrics, (b) Latexes, (c) Lignosulfonates, (d) Petroleum Resins, (e) Plastics, (f) Salts, and (g) Wetting Agents. Representative products from these seven major categories are presented in Appendix B.

Fabrics are not a major form of dust control for tailings. Occasionally, it has been found that cheesecloth, plastic, and burlap type materials have been used for physical cover.

Latexes are an emulsion of rubber or plastic-type materials which act to bind together the surface fines. Latex products are delivered in concentrated form and are diluted with water at levels of 80:1 to 99:1. Latex products have been used throughout the mining industry and two representatives of this category, IDA 656 & 655 distributed by Nalco Chemical Co., were field tested in this study.

Lignosulfonates are by-products of the sulfite pulping process. They are a solution of the lignins and sugars which hold together the cellulose fiber of trees. The lignosulfonate as a

chemical stabilizer is delivered as a 50% solution. For application purposes, this is diluted with water to 4:1 to 12:1. Lignosulfonate products have been used extensively throughout the mining industry for dust control purposes and a representative of this category, Flambinder (calcium lignosulfonate) distributed by Flambeau Paper Co., was field tested in this study.

Petroleum resins are by-products of the oil distillation process. They are usually found as emulsions (40-60% solids), and are diluted with water to 4:1 to 15:1. Petroleum resins have been used extensively for dust control purposes in the mining industry, and a representative, Coherex, distributed by Witco Chemical Co., was field tested in this study.

Plastics, as chemical stabilizers, are usually an emulsion of polymer materials. They are characterized by forming a film over the surface of particles rather than binding together individual particles. Plastic products are delivered in concentrated form and are usually diluted with water to 6:1 to 40:1. Plastics are not widely used as dust control chemicals within the mining industry.

Salts are materials having deliquescent properties, that is, the ability to absorb and retain moisture from the atmosphere. Examples of salts used as chemical stabilizers include magnesium chloride and calcium chloride. They are usually applied without dilution in the liquid concentrated form (approximately 30% solids). Salts are used in the mining industry for dust control purposes, and a representative of this category, magnesium chloride, distributed by Great Salt Lake Mineral and Chemical Co., was field tested in this study.

Wetting Agents or surfactants reduce the surface tension of water enabling it to spread more readily through the surface of the tailings. No mines contacted had used wetting agents as a dust control measure. Wetting agents are used as an ingredient in many chemical stabilizers to aid in the dispersal of the binding products.

### 3.1.3 Application Equipment

As part of the literature search, a number of companies were contacted which manufacture high floatation wheeled vehicles that apply liquid solutions to soil surfaces. These vehicles are primarily marketed as agricultural fertilizer sprayers or municipal sewage treatment plant sludge/land application sprayers. Appendix C presents a summary of the companies contacted. The capacity of the holding tanks on the vehicles range from 1,000 to 2,800 gallons.

Capacity is an important criteria to consider when selecting a vehicle since the larger the capacity the more acreage can be

treated before refilling. Normally, chemical stabilizers are applied at an application dosage of 1,000 gallons per acre. Usually, plants have 50 to 100 acres of tailings to treat, so repeated refilling of the commercially available vehicles is required.

The time required for refilling can be minimized if a larger water truck having premixed chemicals available is positioned near the site of application. This would minimize the travel time required to refill the application vehicle, relative to having to travel to a plant staging area to refill. Vehicles having tires versus tracks were preferred by plant personnel surveyed, because wheeled vehicles can travel faster than tracked vehicles to the refilling site.

The costs of the vehicles range from approximately \$50,000 to \$150,000. In addition, to the application vehicle, ancillary equipment such as storage tanks and associated pumping systems may be required for longterm usage of chemical stabilizers.

### 3.2 Site Surveys

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A number of plants were contacted by telephone and site visit to acquire information concerning the dust control programs for their tailings basins. Appendix D list those companies contacted which shared considerable information.

Based on the information gathered from taconite, copper, uranium/vanadium, and molybdenum plants, a general profile of dust control programs was developed. Almost all of the plants surveyed started dust control programs to either minimize complaints from citizens living near the tailings basins or to comply with the regulations of governmental organizations. Many of the companies had no previous experience in dust control, and experimented, with various degrees of success, with a variety of chemical stabilizers. Some companies have experimented for over 10 years and are still searching for the product to suit their needs.

A problem all companies had to remedy was the type of equipment they could use to apply the chemicals. Normal water wagons, the plants had to spray unpaved plant roadways, did not have the floatation necessary to maneuver over the tailings. Many of the plants constructed their own vehicles to suit their needs.

The plants surveyed had tailings characteristics which were wide ranging. Some plants have tailings with silt contents (that portion of the tailings less than 74 micrometers as determined by dry sieving) ranging from 50 to 90%, while others have tailings ranging in silt content from 5 to 30%.

The meteorological conditions affecting tailings wind erosion varied over the plants surveyed. Most plants experienced their

highest wind speeds in the spring and fall seasons. Plants in the northern United States, where temperatures may get below -20 degrees F, experience freeze-drying of the tailings surface. In these instances, chemical stabilizers are required to mitigate wind erosion caused by winter winds. Some plants are located in areas having considerable rainfall over the wind erosion periods of the year. This rainfall may cause the chemicals to leach from the surface after amounts of 0.5 inch have fallen.

### 3.3 Laboratory Screening Procedures

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Two laboratory tests have been identified to screen chemical stabilizer products in the mining and milling industry and are termed permeability and recovery tests. Permeability tests have been used to determine whether a stabilizer may have an adverse effect on the stability of a tailings dam. The laboratory permeability testing is performed by treating the tailings surface with a chemical stabilizer and recording the rate of water percolating through the treated surface. Subsequent treated layers of tailings are placed over the previously treated surfaces to find whether the repeated chemical treatments affect permeability. For new dams, it is believed by one mining company contacted, that successive applications of certain chemical stabilizers, may impede the ability of water to percolate through the treated layers, creating an overall stability problem.

Recovery testing involves assessing the potential a chemical stabilizer may have in upsetting the critical ore flotation process. Tests are performed consisting of incorporating various concentrations of a chemical stabilizer into the process water, which is used in the floatation/recovery process. Should normal or expected worst case concentration levels of the chemical stabilizer in the process water upset this process, the stabilizer will be removed from further evaluation.

### 3.4 Field Test Plan

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Phase II of the study consisted of field testing representative chemical stabilizers and rating them according to established judgement criteria. A field test plan was developed to establish: the judgement criteria to be used to evaluate the chemical stabilizers, and the methodology for performing the field work.

#### 3.4.1 Evaluation Criteria

There are a variety of generic categories of chemical dust suppressants available for dust control purposes. In the past, for controlling dust emissions from tailings ponds, salts,

lignosulfonates, latexes, and petroleum resins have predominately been used. For the field study, products from these four generic categories were selected for evaluation. The dust control products include: Flambinder (calcium lignosulfonate), Coherex (petroleum resin), Nalco 656 & 655 (latexes), and magnesium chloride (salts).

Table 2 presents the field evaluation criteria which were selected to determine the effectiveness over time of the selected chemical stabilizers.

---

Table 2. Evaluation Criteria

Dust Control Effectiveness: Temporal Wind Erosion  
Threshold Velocity Measurements; Temporal Emission  
Factor Measurements

Meteorology: Precipitation; Wind Speed; Freeze/Thaw

Tailings Characteristics: Spatial and Temporal Silt and  
Moisture Content Variations

Product Usage Requirements: Delivery; Storage; Application  
Procedures

Costs: Product; Shipping; Labor; and Equipment

Cost Effectiveness: Dollars Expended Per Acre To Achieve  
An Acceptable Level of Control Over Time

---

### 3.4.2 Field Testing Methodology

The basic procedure developed for evaluating the various chemicals was to apply them at one location, side-by-side, on one half acre test plots. Each type of chemical was to be evaluated at the vendor or industry normal application dosage level and at an alternate dosage level. This variation was to test the apparent sensitivity of dosage level to control effectiveness.

The means to test the effectiveness of the chemical stabilizers employed two procedures. First, an in-situ portable field wind tunnel was used to: (a) determine the threshold velocity, (that speed of the wind which initiates the wind erosion process), and (b) determine dust emission factors over time at various simulated wind speeds. A real-time cascade impactor was used to collect isokinetic particle samples from the wind tunnel.

The second means of determining product control effectiveness was to measure the silt content over time of the treated tailings. Since the chemical stabilizers selected for the field study bind together surface fines, an increase of silt content after chemical application, should be related to decreases in control efficiency as measured by the threshold velocity of the wind tunnel.

Field testing was proposed immediately after product application and at two week intervals thereafter. It was proposed that during each field measurement period each test plot be tested to: (a) determine the wind erosion threshold velocity, (b) obtain dust emission factors at velocities higher than the threshold (equivalent 10 meter high velocities of 20, 30, 40, and 50 mph), and (c) collect representative surface tailings samples to determine the silt and moisture content of the stabilized tailings.

## 4.0 FIELD TESTING

Four major types of chemical stabilizers were evaluated under field conditions. The chemical stabilizers included a petroleum resin, lignosulfonate, latex, and salt product.

The following sections describe the procedures followed for the field evaluation of the chemicals including; preparation, chemical application, and field sampling procedures.

### 4.1 Preparation

-----

#### 4.1.1 Site Selection

Based on the information gathered from the field trips performed in Phase I, it was decided the location for the field testing of the chemical stabilizers be performed in the Mesabi Iron Range of northern Minnesota. This general location was chosen because of the numerous plants from which to choose to perform the testing, and the availability of proper chemical application equipment.

Three plants within the Mesabi Iron Range were surveyed during the week of May 10, 1982. Based on the results of the survey, the tailings basin at the National Steel Pellet Company located near Keewatin, Minnesota was chosen. The plant had numerous areas of accessible untreated tailings which could be set aside prior to revegetation, for the application of test chemical stabilizers. Plant personnel agreed to vegetate the immediate areas surrounding the test plots to mitigate the deposition of wind blown tailings onto the treated test plots.

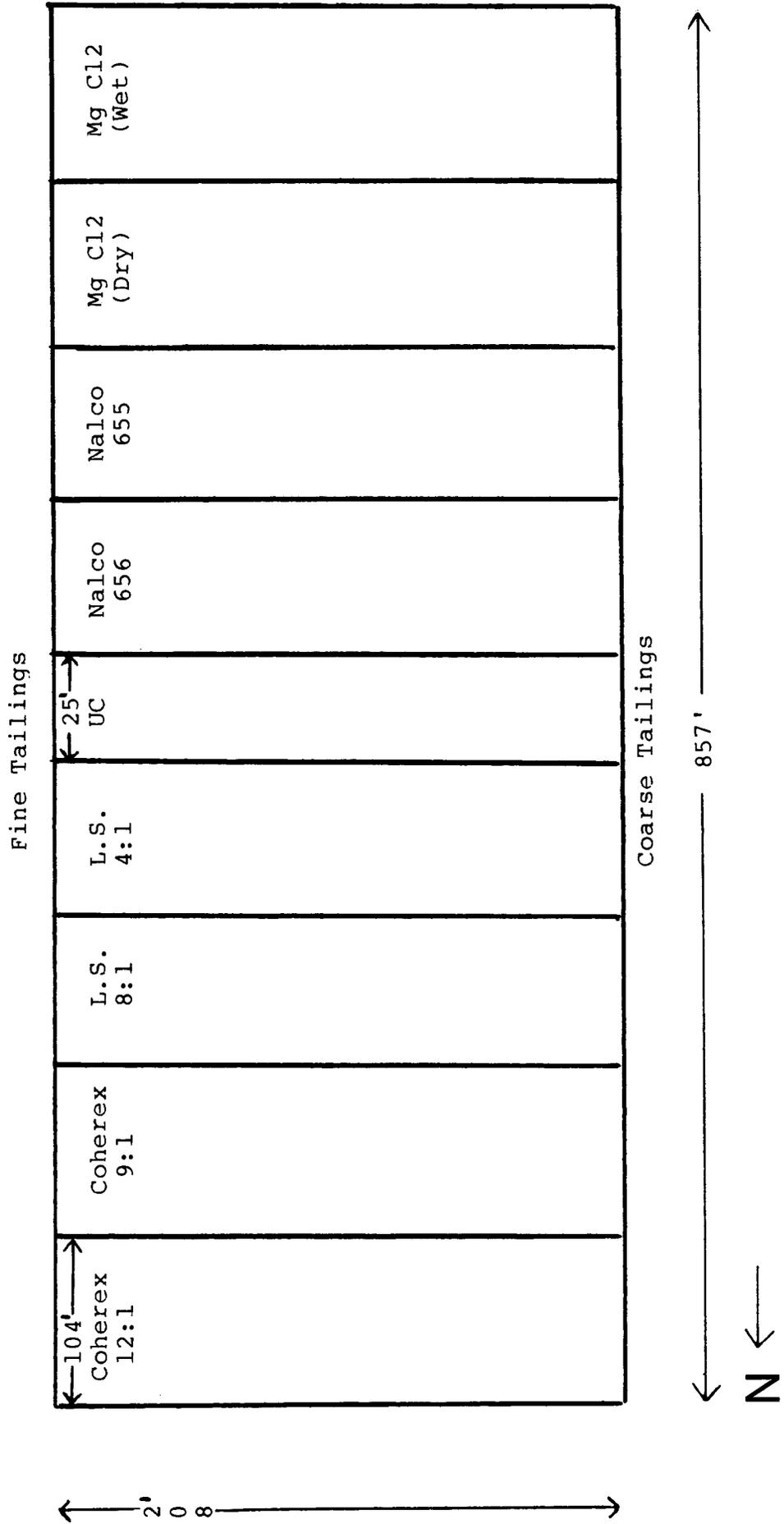
#### 4.1.2 Test Plot Location And Size

The area used for the test plots were 857 feet in length and 208 feet wide, or approximately four acres overall. The individual test plots were 104 feet wide by 208 feet in length, approximately one half acre in size. The uncontrolled test plot was 25 feet wide by 208 feet in length and located in the center of the test plot area. Figure 1 presents the general layout of the test plot area.

The test plot area was located in a large open tailings field partially re-vegetated and interdispersed with outcroppings of dead, partially covered trees. To the north and south boundaries were open areas of tailings, while the east was bounded with trees. The west side of the test plot area was bounded by a slope resulting from the old spigot line. The tailings were

Figure 1.

TEST PLOT LOCATION AND SIZE



generally coarser near the west end of the plot and finer near the east. Figure 9, in Section 4.3.3, presents the surface silt content of the tailings test plots prior to chemical stabilizer application. A slight slope was evident running from west to east.

The test plots were oriented in a north/south direction with Coherex 12:1 being the farthest north plot and magnesium chloride-wet being the most southern.

#### 4.1.3 Chemical Stabilizers Selected

Four major types of chemical stabilizers were evaluated during the field testing. Table 3. presents the chemical stabilizers.

-----  
 Table 3. Chemical Stabilizers Evaluated For Effectiveness

Type -----	Product -----	Vendor -----
Petroleum Resin	Coherex	Witco Chemical Co.
Lignosulfonate	Calcium Lignosulfonate	Flambeau Paper Co.
Latex	Nalco 656 & 655	Nalco Chemical Co.
Salt	Magnesium Chloride	Great Salt Lake Minerals & Chemicals Corp.

-----

Coherex and calcium lignosulfonate were chosen due to their prevalent use within the mining industry. The two Nalco Chemical Co. products were chosen as a representative of the latex group of dust control chemicals and because they are starting to be used throughout the mining industry. The magnesium chloride, a relatively new product compared to Coherex and the lignosulfonate, was chosen as a representative of the salt group of dust control chemicals. Magnesium chloride has just recently been marketed as a dust control chemical for the mining industry.

#### 4.2. Application Of Chemical Stabilizers

-----

The various chemical stabilizers were applied onto the surface of the tailings with a specialized spray vehicle. Bagley Sodding Co. of Bemidji, Minnesota was contracted to apply the chemicals. The vehicle they used for application was an Ag-Chem Co.

Ag-Gator 1004, high floatation spray vehicle. The unit had a 1,000 gallon holding tank with internal mixing capabilities to keep the chemicals in solution after they were diluted with water. The spray boom on the vehicle was 50 feet in length and was capable of applying chemical at a spray pressure of up to 40 pounds per square inch. The floatation rating of the vehicle was 14 pounds per square inch.

The selected chemical stabilizers were applied on eight half acre plots. Two application dosages were tried per chemical, except for the magnesium chloride. This was done to note differences within the intensity of application per chemical. Table 4 presents the application dosage and dilution ratio of the applied dust control chemicals.

-----  
 Table 4. Chemical Stabilizer Application Data

Chemical	Application: Dosage (gal/yd <sup>2</sup> )	Dilution (H <sub>2</sub> O:Product)
-----	-----	-----
Coherex	0.25	12:1
Coherex	0.25	9:1
Calcium lignosulfonate	0.25	8:1
Calcium lignosulfonate	0.25	4:1
Nalco 655	0.25	98:2
Nalco 656	0.25	99.25:0.75
Magnesium chloride	0.50 (a)	65:35 (c)
Magnesium chloride	0.50 (b)	65:35 (c)

(a) Product was applied directly to dry tailings

(b) Tailings surface was wetted to a depth of 1/2 inch prior to applying the product.

(c) Applied as a 35% brine, as received from the vendor.

-----

The above application dosages and dilution ratios were obtained either from the product vendors or from information gathered from mining personnel who have used the products in the past. Aside from the two Nalco products, the second of the application/dilution data for the chemicals in Table 4 is the recommended usage for the chemicals. The first application/dilution values for the chemicals are alternate values selected to note what effect altering the amount of chemical applied would have on control effectiveness.

For the magnesium chloride the amount of chemical applied was not altered, however, the manner of application was. It was recommended by the product vendor that the surface of the tailings be wetted approximately 1/2 inch prior to chemical application. This wetting of the surface aids the dispersal of

the chemical throughout the surface, as well as providing the moisture necessary to trigger the deliquescent properties of the chemical. To test whether the wetting of the tailings surface was necessary to achieve efficient control, one test plot was properly wetted and one test plot was left dry, prior to application.

For the Nalco Chemical Co. products, the application/dilution strengths of one specific chemical were not altered, however, two similiar products were evaluated.

The time required to place the chemicals on the test plots was two days. Considerable time was spent in cleaning the tank and other parts of the application vehicle when changing chemicals. This was done to mitigate any chemical reactions which could occur from residual chemical left in the holding tank. The magnesium chloride had an unknown substance in solution which clogged the spray nozzles of the application vehicle. Considerable time was spent in cleaning the spray nozzles and cleaning the interior of the holding tank to remedy the problem. The unknown substance was later identified as an ammonium chloride precipitate. The reason the precipitate was found in the solution was not identified.

Figures 2 and 3 present photographs of the field application of the chemical stabilizers and a portion of the tailings which were recently treated with dust control products.

### 4.3 Field Sampling Procedures

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#### 4.3.1 Equipment

The primary instrument which was used to measure the long term effectiveness of the chemical stabilizers is the ES&T portable field wind tunnel as described in Figure 4. The wind tunnel is very similiar in design as the wind tunnel developed by the National Center For Atmospheric Research (NCAR)(1). The wind tunnel has an open bottom working section constructed of clear Lucite SAR having interior dimensions of 96 inches by 6 inches. As air is drawn into the inlet of the wind tunnel, it is straightened and develops turbulence as it proceeds through the working section. The developing turbulence erodes the tailings surface particles. Wind speeds up to 50 mph can be generated within the six inch high tunnel working section. This air velocity is equivalent to approximately 80 mph at an extrapolated height of 10 meters.

After the working section, the particle laden air enters the test section of the wind tunnel. Here the airflow is straightened and slowed to enable isokinetic particle sampling. A sample flow splitting device is used to collect representative



Figure 2 Application of Chemical Stabilizers

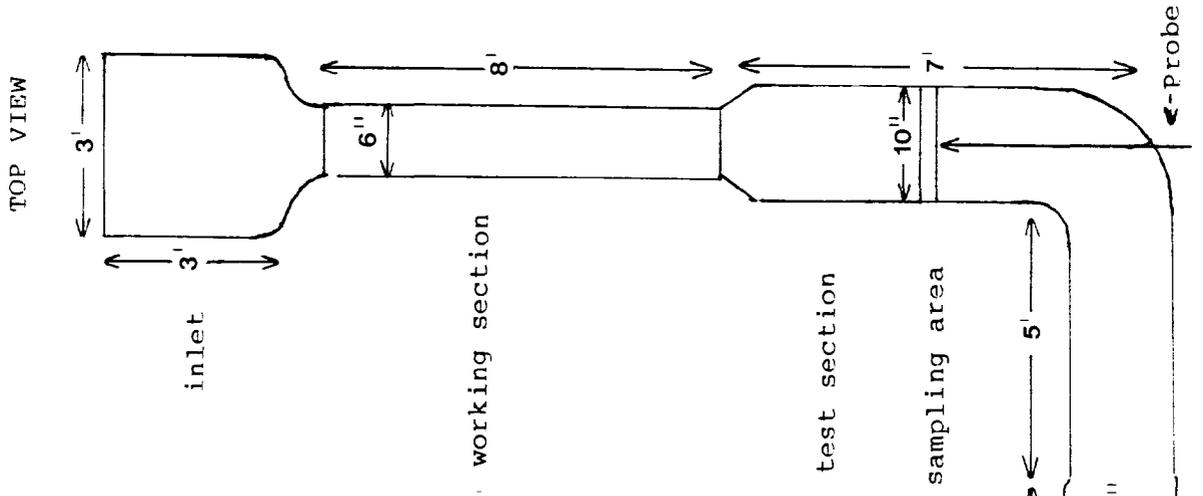
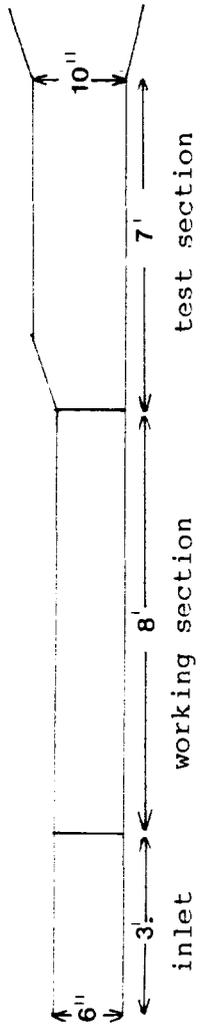
The application vehicle is an Ag-Chem Co., Ag-Gator 1004. The vehicle has a 1,000 gallon holding tank with a spray boom having 11 spray nozzles and an overall length of 50 feet. The floatation rating of the vehicle is 14 pounds per square inch. The vehicle in the photograph is starting to apply a chemical stabilizer onto a portion of a 208 by 104 foot test plot. The area to the immediate right of the spray pattern is a test plot treated with another chemical stabilizer within the last 24 hours. The area ahead of the vehicle has not been previously treated. Although the area of the test plot, which is being sprayed, appears noticeably wet, the chemical stabilizer is absorbed readily by the dry, fine tailings.



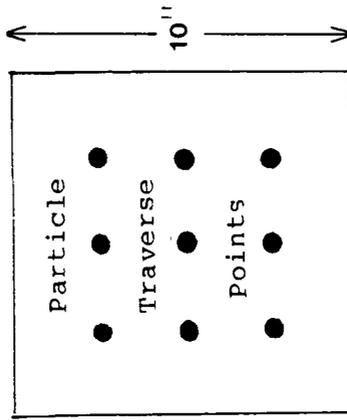
Figure 3 Test Plot Areas Treated With Chemical Stabilizers

The test plot area (the tailings surface which is noticeably dark) is photographed, looking east, from the location of the old spigot line. The treated plot area is 208 feet in distance from the foreground to the general area of the trees. The tailings in the foreground are coarser in texture than the treated tailings. The tailings in the areas of the partially covered trees are finer in texture than the treated tailings. Shown in the photograph are two recently treated areas, Coherex to the left and lignosulfonate to the right. The tire tracks of the application vehicle are noticeable. The vehicle tires left an impression in the tailings of a depth of one inch.

SIDE VIEW



SAMPLING AREA CROSS SECTION



ES&T FIELD WIND TUNNEL

Figure 4.

particulate sample (2). Sampling velocities in the test section range from 5 mph to 20 mph. The position of the particle sampling inlet nozzle is eight diameters downstream from any bend or constriction and two diameters upstream from any disturbance. This allows for sampling in non-turbulent air flow.

The particle sampling instrument used in the study was the California Measurements, PC-2 Cascade Impactor. This instrument operates with a quartz crystal for an impactor stage allowing for near real-time display of sampled particle concentration and aerodynamic particle size distribution. The detection level of the instrument is quite sensitive, enabling the operator to obtain an adequate sample in a brief time period (2,3).

A standard pitot tube was used to measure the velocity in both the working and test sections of the wind tunnel. A portable, 2000 watt electric generator was used for power. The instrumentation was moved over the tailings by means of a 4-wheel drive pickup truck.

Figures 5 and 6 present photographs of the wind tunnel and the cascade impactor used for the field sampling.

#### 4.3.2 Wind Tunnel Testing Procedure

The portable field wind tunnel was used to quantify over time the decay in the effectiveness of the chemical stabilizers. Six test periods, scheduled evenly over a four month period, were used to determine the decay rate. This time period of four months corresponds with the typical length of time the chemical stabilizers were believed to be effective.

The testing procedure utilizing the wind tunnel follows:

1. After the tunnel has been assembled and checked for air leakage in the working section, the air speed in the tunnel is slowly raised to the point where surface particles in the working section begin to visibly move. This velocity is termed the threshold velocity.
2. The air flow is slowed to below the threshold and a vertical velocity profile of the air flow is taken within the the working section. This velocity traverse will identify the slope of the logarithmic wind profile within the 15.2 centimeter (6 inch) high tunnel working section. Traverse points are taken at heights above the ground of 0.5, 1.0, 2.0, 3.8, 7.6, 10.0, and 15.0 centimeters. From this profile,  $Z_0$ , or the height above the ground at which the horizontal air speed is zero mph, is determined by extrapolation. An example is shown in Figure 7.

$Z_0$  is used to determine what centerline (7.6 centimeter



Figure 5 Environmental Services & Technology Field Wind Tunnel

The field wind tunnel is deployed on recently treated tailings. In the foreground is the inlet. Refer to Figure 4 for dimensions. Following is the 8 foot long by 6 inch square open bottom plexiglass working section. It is here that the tailings surface is eroded by the generated air velocity. Onto the sides of the working section are weighted-down nylon flaps which impedes air infiltration from the edges of the working section. Following the working section is the expansion to the test section where the eroded dust particles are collected with a cascade impactor. In the area where the probe for the cascade impactor enters the test section, a bend in the tunnel occurs to facilitate direct probe entry. Following the bend is the flexible line attached to the fan, which creates the air velocity through the wind tunnel. All the equipment can be placed in the bed of the four-wheel drive pickup for transportation between test sites.

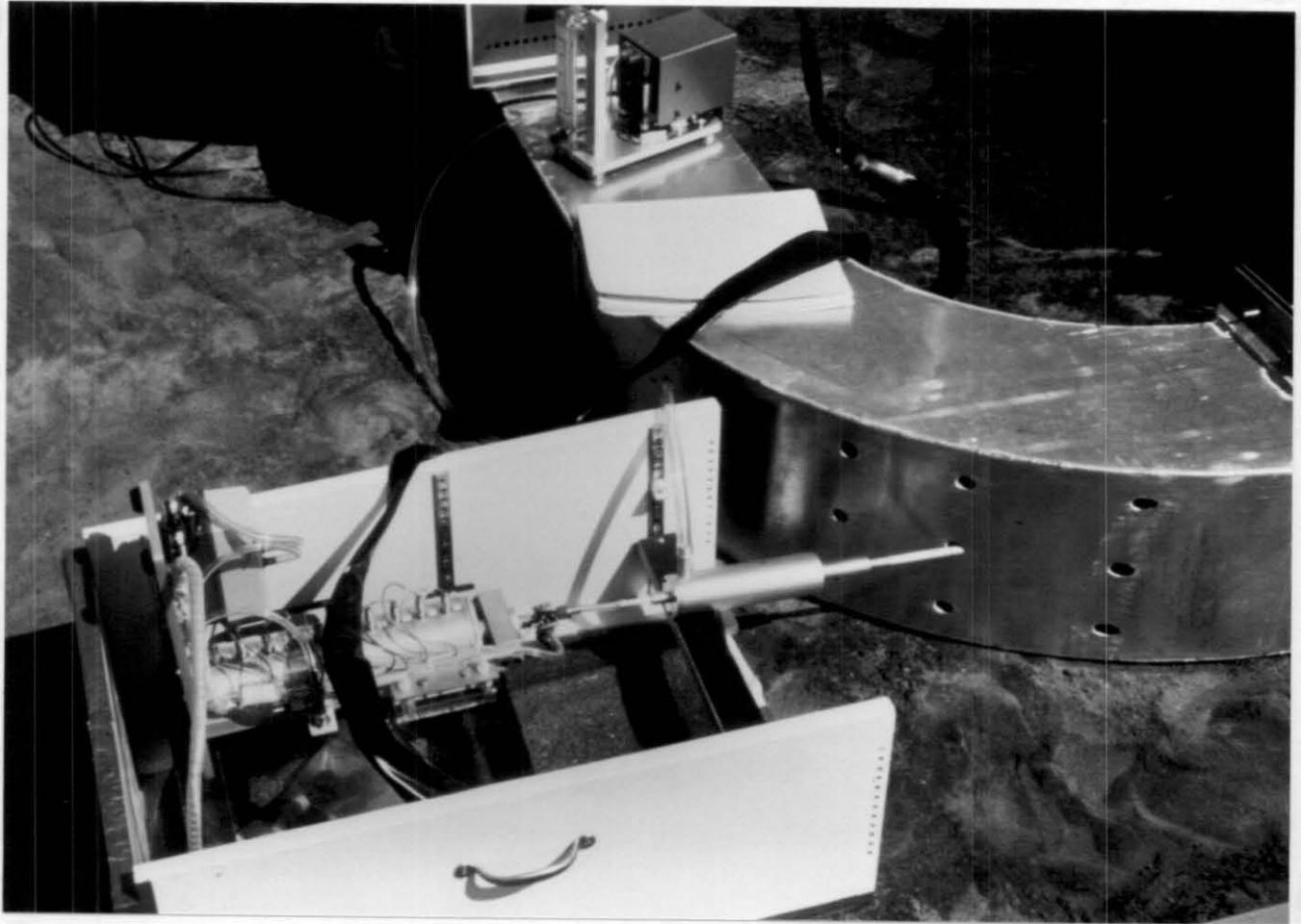
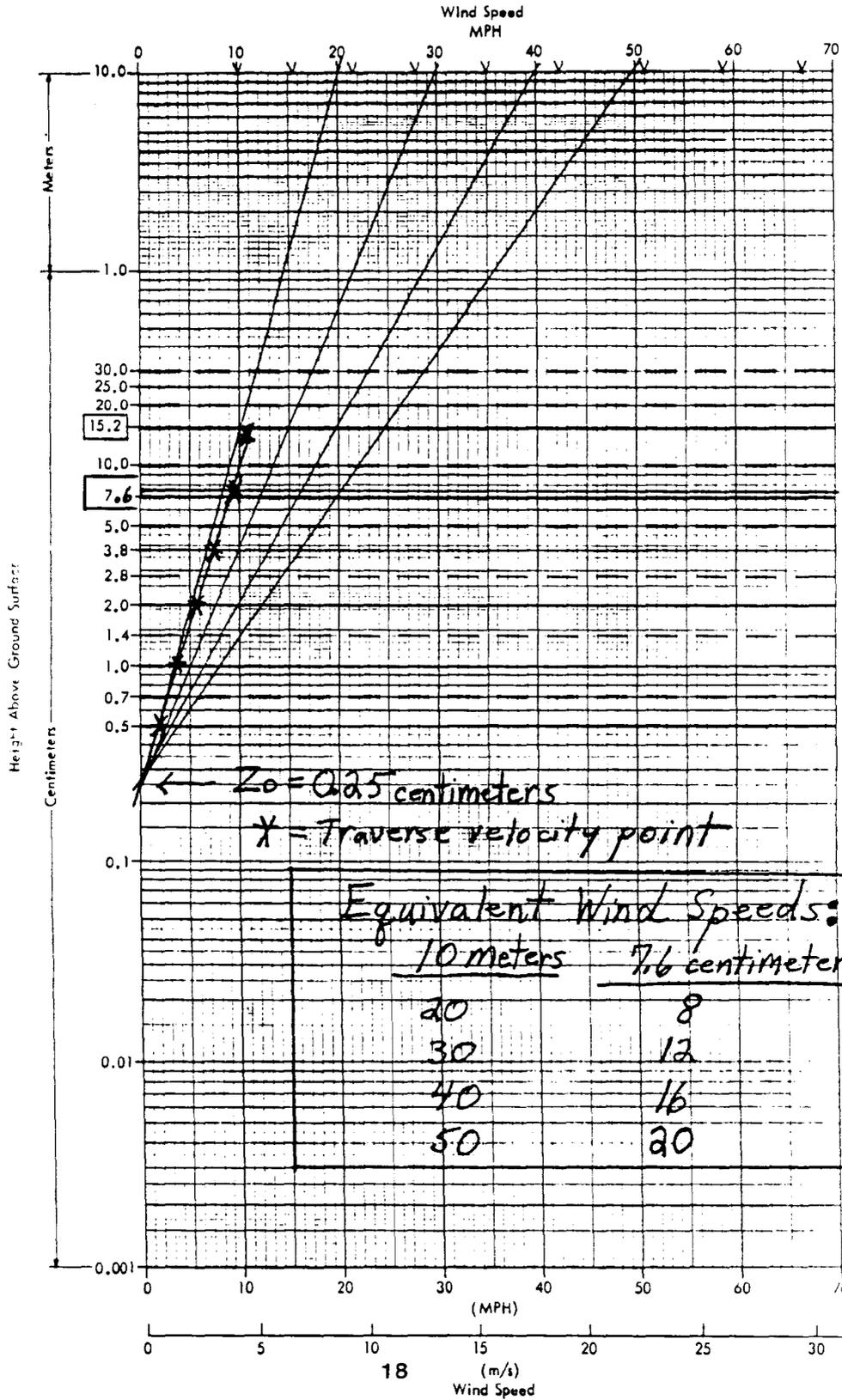


Figure 6 Cascade Impactor - Particle Sampling Instrument

The cascade impactor which sizes the collected particles in ten stages, ranging from  $>25$  micrometers to  $<0.1$  micrometers in aerodynamic diameter, is placed at the bend of the wind tunnel test section. Refer to Figures 4 and 5. At the bend there are nine evenly spaced sampling points, which are required for representative sampling. The dust entrained air enters the probe, placed 40 inches before the bend, enabling sampling in a near laminar flow region. The cylindrical device attached to the probe (center of picture), is the sample flow splitter. Here a representative portion of the particles which have been collected and transported by the probe are isokinetically split from the general probe air flow and are entered directly into the 10 stage real-time cascade impactor. A small pump with rotameter, setting on top of the wind tunnel, is used to create the flow for the sample splitter/probe combination. The flow rate through this pump is varied in order to achieve isokinetic conditions at the point where the dust entrained air flow enters the sampling probe in the test section. The pump for the flow rate of the cascade impactor (250 milliliters per minute) is attached to the base of the unit.

Figure 7 Velocity Profile

Run No. \_\_\_\_\_ Wind Erosion Testing Date \_\_\_\_\_  
 Project No. \_\_\_\_\_ Wind Speed Vertical Profile Recorded by \_\_\_\_\_



or three inch high) velocity in the working section is equivalent to a wind speed as measured at a height of 10 meters. The 10 meter height is a standard height for U.S. Weather Service wind speed instrumentation. This equivalency is based on the assumption that the vertical profile of the extrapolated wind speeds is logarithmic from the tailings surface to a height of 10 meters (4).

Determination of these equivalent 10 meter wind speeds is performed by plotting lines from  $Z_0$  to the 10m wind speeds of 20, 30, 40 and 50 mph. The intersection of these lines at the height of 7.6 centimeters delineates the equivalent air velocity at the center of the working section relative to the 10 m height.

4. The air sampling procedure consists of performing a nine point particle collection traverse within the 10 inch square sampling section. The procedure is similar to EPA Test Procedure Method 5 (5). The isokinetic particle traverses are performed at equivalent 10 m air velocities of 20, 30, 40, or 50 mph. The working section of the wind tunnel is moved, a few feet for every new velocity test, in order to sample surface material from which the fines have not been removed by the previous different air speeds.
5. For each test, ambient background particle concentrations are obtained. To acquire these samples, the cascade impactor samples isokinetically the ambient air which enters the inlet of the wind tunnel. These particle concentrations are subtracted from the concentrations measured at each point within the wind tunnel, to obtain net wind erosion particle concentrations.

Figure 8 presents a photograph of the wind tunnel during the sampling process.

#### 4.3.3 Tailings Silt/Moisture Sample Collection And Analysis

Surface samples of the tailings test plots were collected throughout the duration of the field work in order to characterize the amount of silt and moisture present. This information was later used to determine whether there exists a relationship between the silt content of the tailings and the wind erosion threshold velocity.

Initially, four samples were taken on each of the test plots prior to the application of the chemicals. These samples transected the plots in length and enabled identification of the original or baseline silt content. Figure 9 presents this baseline silt content information. After chemical application, surface tailings samples were taken for every completed test



Figure 8 Wind Tunnel Operation

The photograph presents a part of the data acquisition procedure for the velocity profile measurements within the working section of the wind tunnel. The individual near the plexiglass working section is positioning the pitot tube at a specified height above the tailings surface. The pitot tube will measure air velocity at this point. Subsequent velocity points at other heights in the working section are obtained in order to determine the vertical profile of the air velocity. The individual near the test section, is reading the velocity from a manometer. In the right foreground of the photograph is the cascade impactor, presented in Figure 6. In the center foreground is the microprocessor for the real-time cascade impactor. The microprocessor controls the sample run time, calculates the particle concentrations for the cascade impactor, and prints a histogram of the particle size distribution.

Figure 9 UNCONTROLLED TAILINGS SILT CONTENT

Fine Tailings

Coherex 12:1	Coherex 9:1	L.S. 8:1	L.S. 4:1	UC	NaIco 656	NaIco 655	Mg Cl2 (Dry)	Mg Cl2 (Wet)
34.5	21.9	6.2	5.6	1.1	6.7	13.7		
11.4	14.1	5.3	5.8	4.9	12.7	7.2	5.9	5.8
17.2	6.5	7.5	9.4	0.20	5.3	7.8	10.7	11.6
	6.4	6.3	7.8	3.8	6.1	6.3	25.7	21.7

Coarse Tailings

run.

Samples were collected by lightly sweeping with a hand brush, an area approximately one foot wide by three feet long. Care was taken to remove only the upper 1-3 millimeters of the tailings. The tailings were then placed in a plastic sample container, labeled, and sealed for transport to the analysis laboratory. Approximately 500-1,000 grams of sample were collected.

Prior to the sieving process, the samples were weighed and placed in an oven at 225 degrees Fahrenheit for eight hours. After drying, the samples were reweighed and percent moisture content was calculated.

After drying, the samples were sieved for thirty minutes using a sieve shaker with preweighed ASTM brass sieve screens of 20, 40, 100, 140, and 200 mesh (ASTM Method C-136) (6). After sieving, the screens were reweighed and the percent passing each screen size was determined. The percent passing the number 200 mesh screen is defined as silt content. Silt sized particles are less than 74 micrometers in physical diameter and are readily suspended during wind erosion periods.

The silt content of a fugitive dust source, as measured by the dry sieving process, has been shown to be one of the independent parameters which governs the intensity of dust emissions (7,8,9).

## 5.0 COMPARATIVE EVALUATION OF CHEMICAL STABILIZERS

### 5.1 Dust Control Effectiveness

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The effectiveness over time of the applied chemical stabilizers was determined by measurements taken with the portable field wind tunnel. Measurements were taken over a four month time period. Two measurements which show relative effectiveness are the wind erosion threshold velocity and the mass emission factor.

#### 5.1.1 Wind Erosion Threshold Velocities

The wind erosion threshold velocity is the air speed at which the tailings first start to move, the point where saltation occurs. As the bonding strength of a chemical stabilizer weakens over time, the point at which erosion initiates is associated with decreasing air velocity. Relative control effectiveness over time can be determined, if threshold velocity measurements are performed at intervals throughout the lifetime of the applied chemical stabilizer.

Figures 10 to 15 present the wind erosion threshold velocities for each of the applied chemicals measured during each of the six completed measurement periods. This series of figures shows the relative effectiveness of all the chemicals per test period. The reference height for the velocity measurement was three inches, the midpoint height of the working section of the wind tunnel. Figures E1-6 are presented in Appendix E, with an extrapolated threshold velocity measurement height of 10 meters. This is the height most commonly referred to when discussing ambient wind speeds. As an aid in evaluating Figures 10 to 15, the three inch height threshold velocities can be multiplied by a factor of 1.5 to approximate an equivalent 10 meter height wind speed.

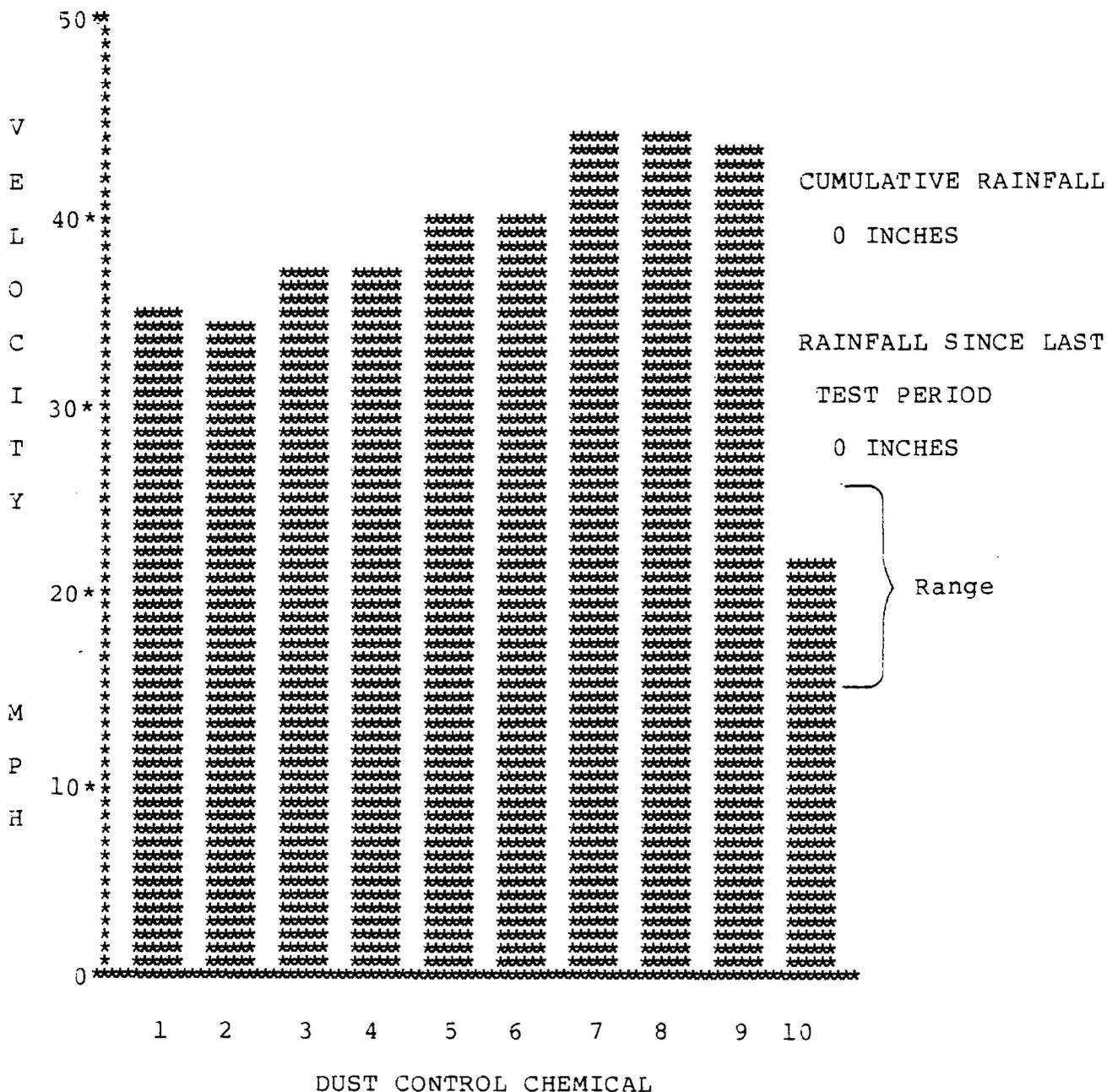
Additionally, Figures 10 to 15 present the cumulative rainfall and the rainfall since the preceding test period. The effect rainfall has on the chemical stabilizers will be discussed in Section 5.2

The last bar of data presented on Figures 10-15 (No. 10) is the mean uncontrolled threshold velocity. The range of the uncontrolled tailings threshold velocities was 15 to 26 mph. The variation of the uncontrolled threshold velocities was due to the range of associated tailings silt content values (14.7 to 0.8%, respectively) measured during the field testing, as presented in Table 11 in Section 5.3. As will be explained in Section 5.3, higher threshold velocities are associated with lower silt content or coarser tailings.

Figure 10.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 1 (5/28)

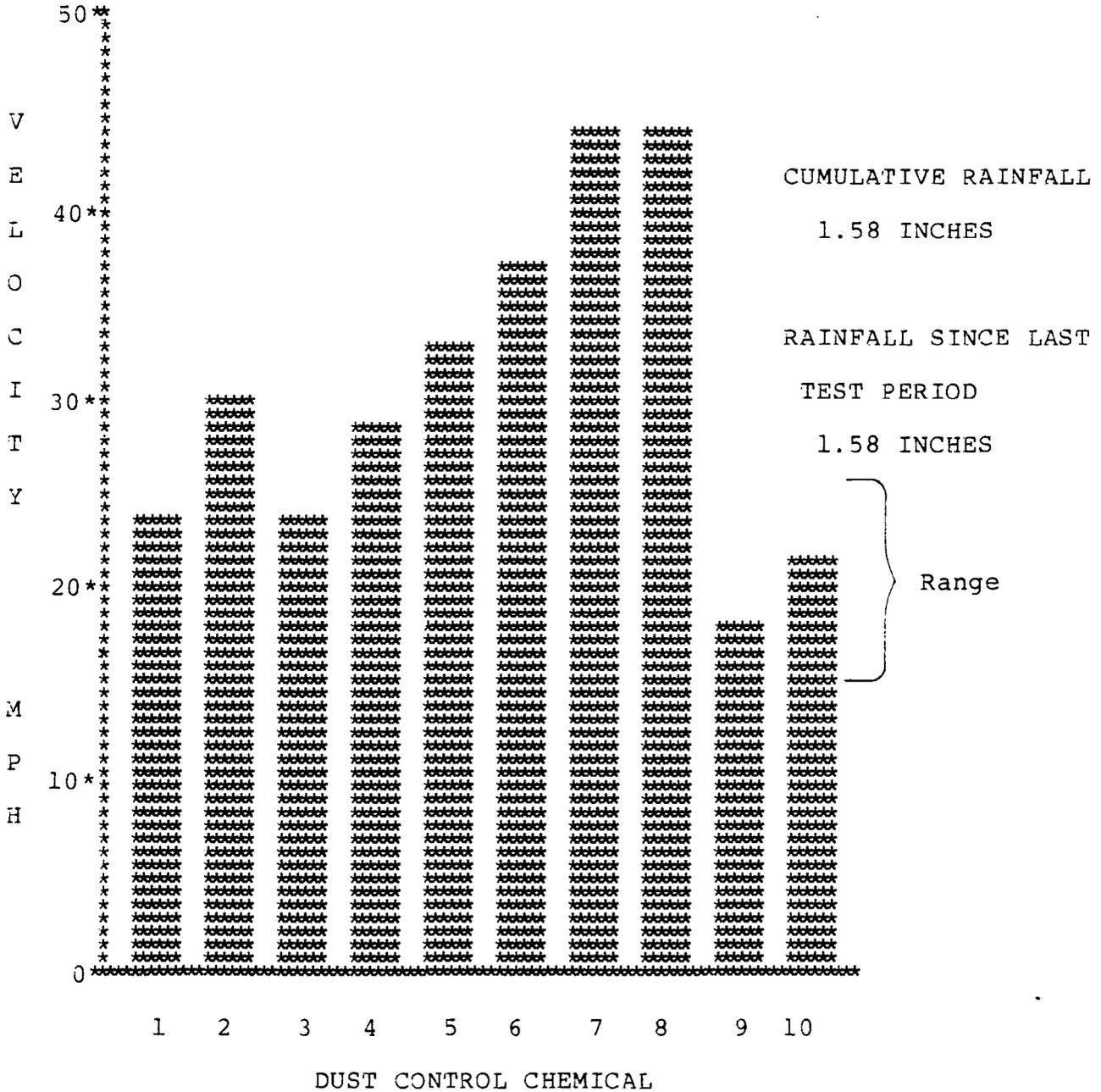
(VELOCITY @ 3 INCH HEIGHT)



- |   |                    |    |                             |             |
|---|--------------------|----|-----------------------------|-------------|
| 1 | Coherex 12:1       | 6  | Nalco 655                   | (Tested On) |
| 2 | Coherex 9:1        | 7  | Magnesium Chloride Wet, Wet |             |
| 3 | Lignosulfonate 8:1 | 8  | Magnesium Chloride Dry, Dry |             |
| 4 | Lignosulfonate 4:1 | 9  | Magnesium Chloride Dry, Dry |             |
| 5 | Nalco 656          | 10 | Uncontrolled Mean           |             |

Figure 11.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 2 (6/15)  
 (VELOCITY @ 3 INCHES)

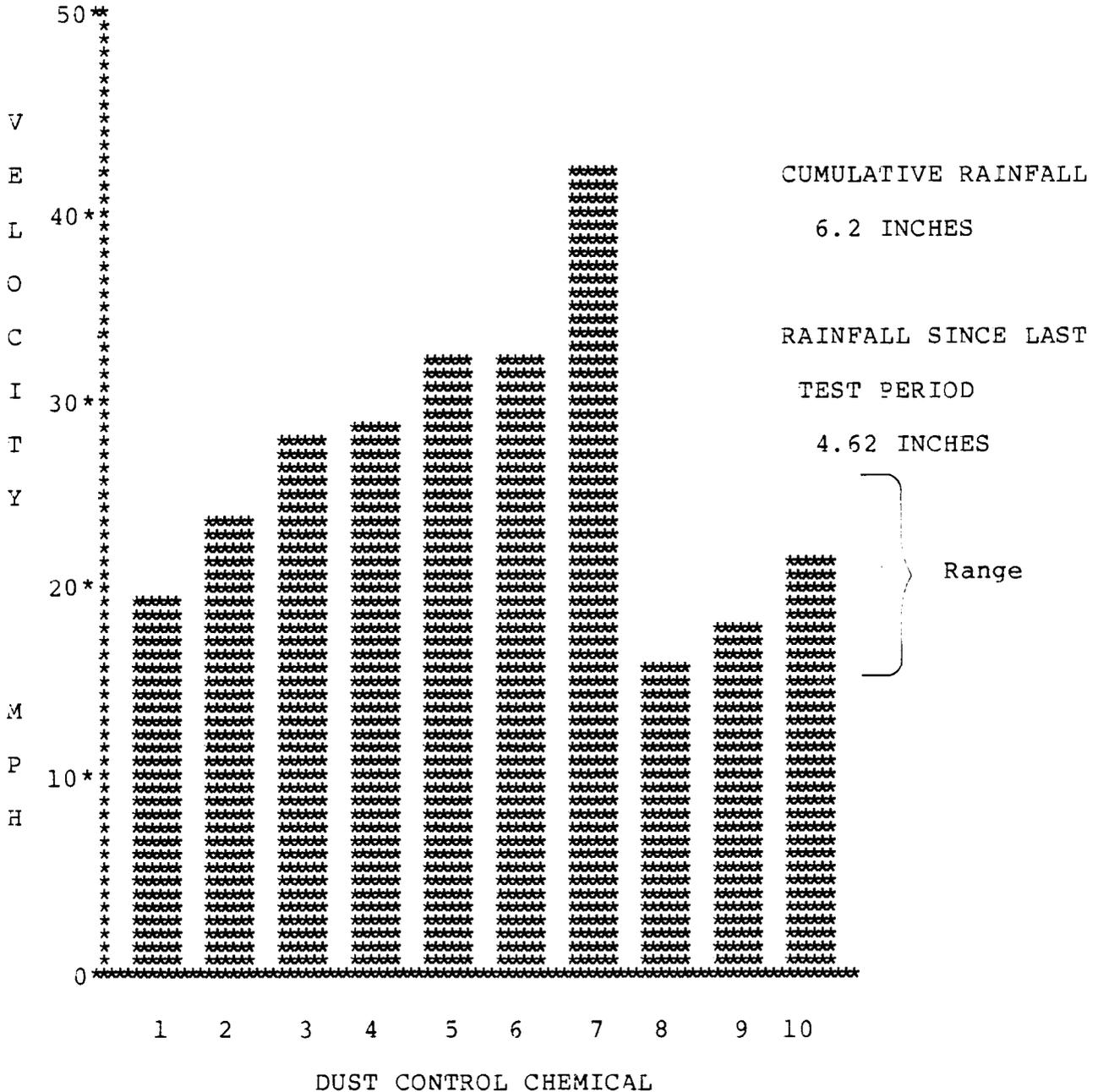


- 1 Coherex 12:1
- 2 Coherex 9:1
- 3 Lignosulfonate 8:1
- 4 Lignosulfonate 4:1
- 5 Nalco 656
- 6 Nalco 655 (Tested On)
- 7 Magnesium Chloride Wet, Wet
- 8 Magnesium Chloride Dry, Dry
- 9 Magnesium Chloride Dry, Dry
- 10 Uncontrolled Mean

Figure 12.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 3 (7/8)

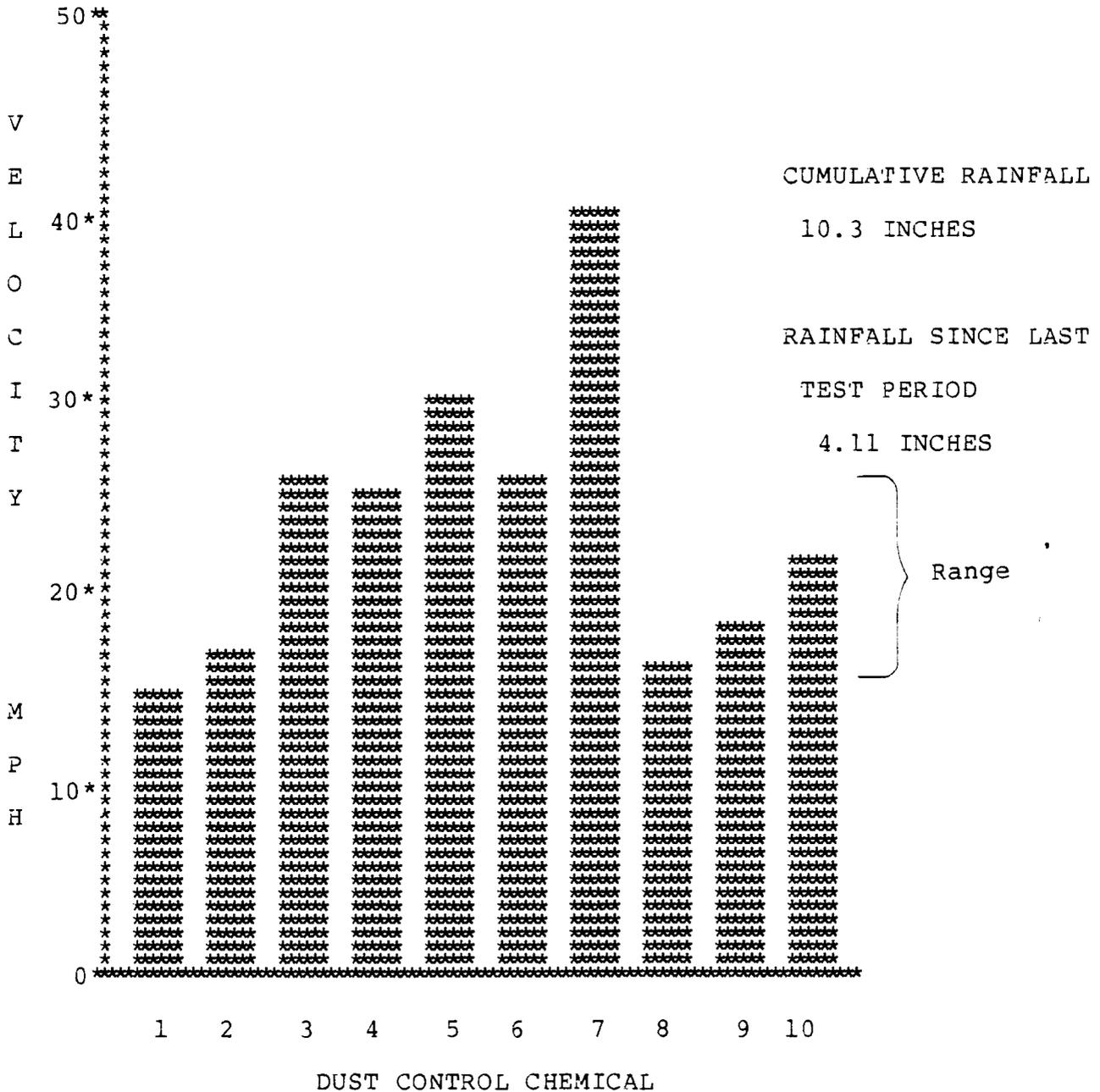
(VELOCITY @ 3 INCH HEIGHT)



- |   |                    |    |                    |             |
|---|--------------------|----|--------------------|-------------|
| 1 | Coherex 12:1       | 6  | Nalco 655          | (Tested On) |
| 2 | Coherex 9:1        | 7  | Magnesium Chloride | Wet, Wet    |
| 3 | Lignosulfonate 8:1 | 8  | Magnesium Chloride | Dry, Dry    |
| 4 | Lignosulfonate 4:1 | 9  | Magnesium Chloride | Dry, Dry    |
| 5 | Nalco 656          | 10 | Uncontrolled Mean  |             |

Figure 13.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 4 (7/31)  
 (VELOCITY @ 3 INCH HEIGHT)

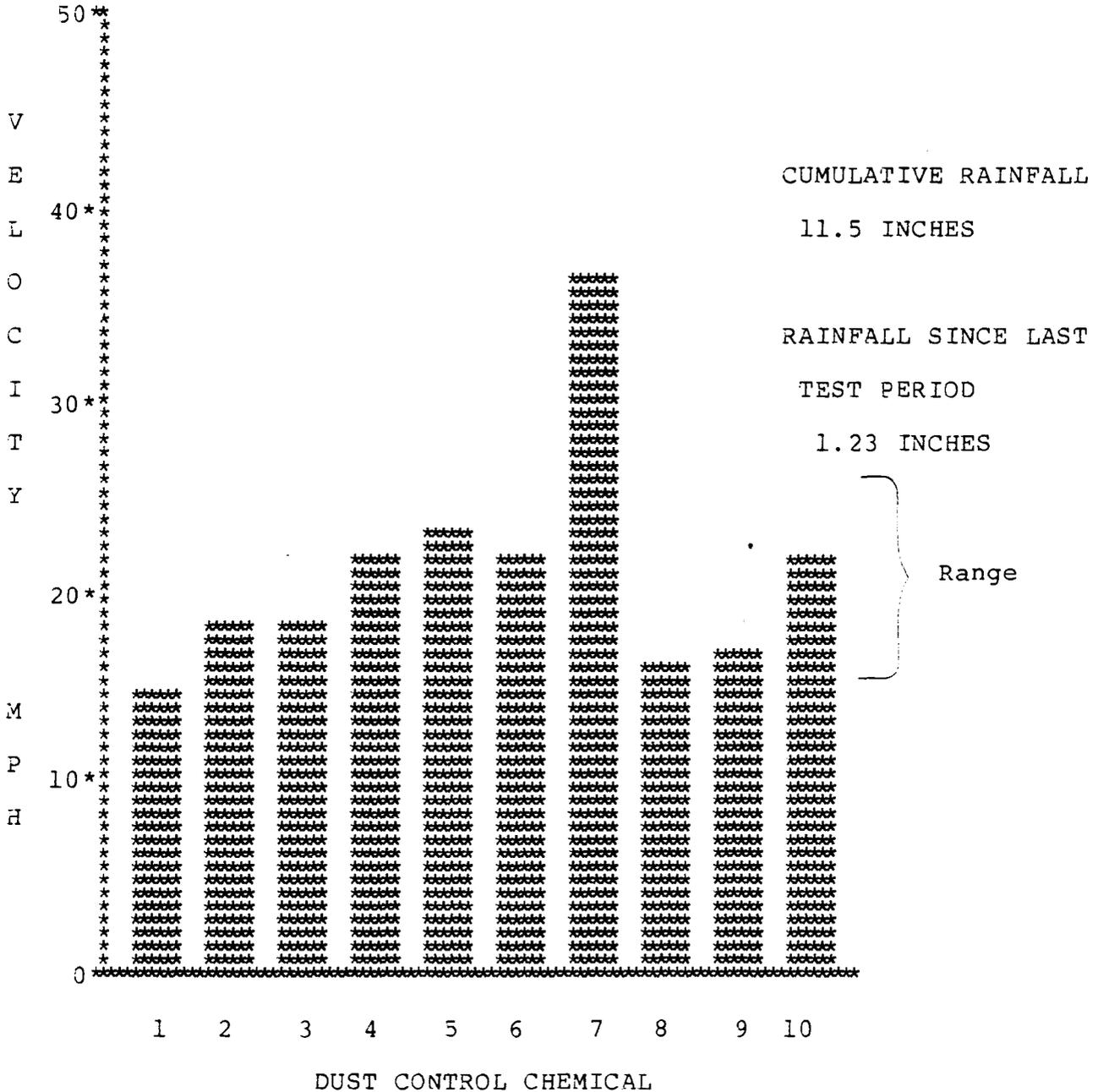


- |   |                    |    |                    |             |
|---|--------------------|----|--------------------|-------------|
| 1 | Coherex 12:1       | 6  | Nalco 655          | (Tested On) |
| 2 | Coherex 9:1        | 7  | Magnesium Chloride | Wet, Wet    |
| 3 | Lignosulfonate 8:1 | 8  | Magnesium Chloride | Dry, Dry    |
| 4 | Lignosulfonate 4:1 | 9  | Magnesium Chloride | Dry, Dry    |
| 5 | Nalco 656          | 10 | Uncontrolled       | Mean        |

Figure 14.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 5 (8/17)

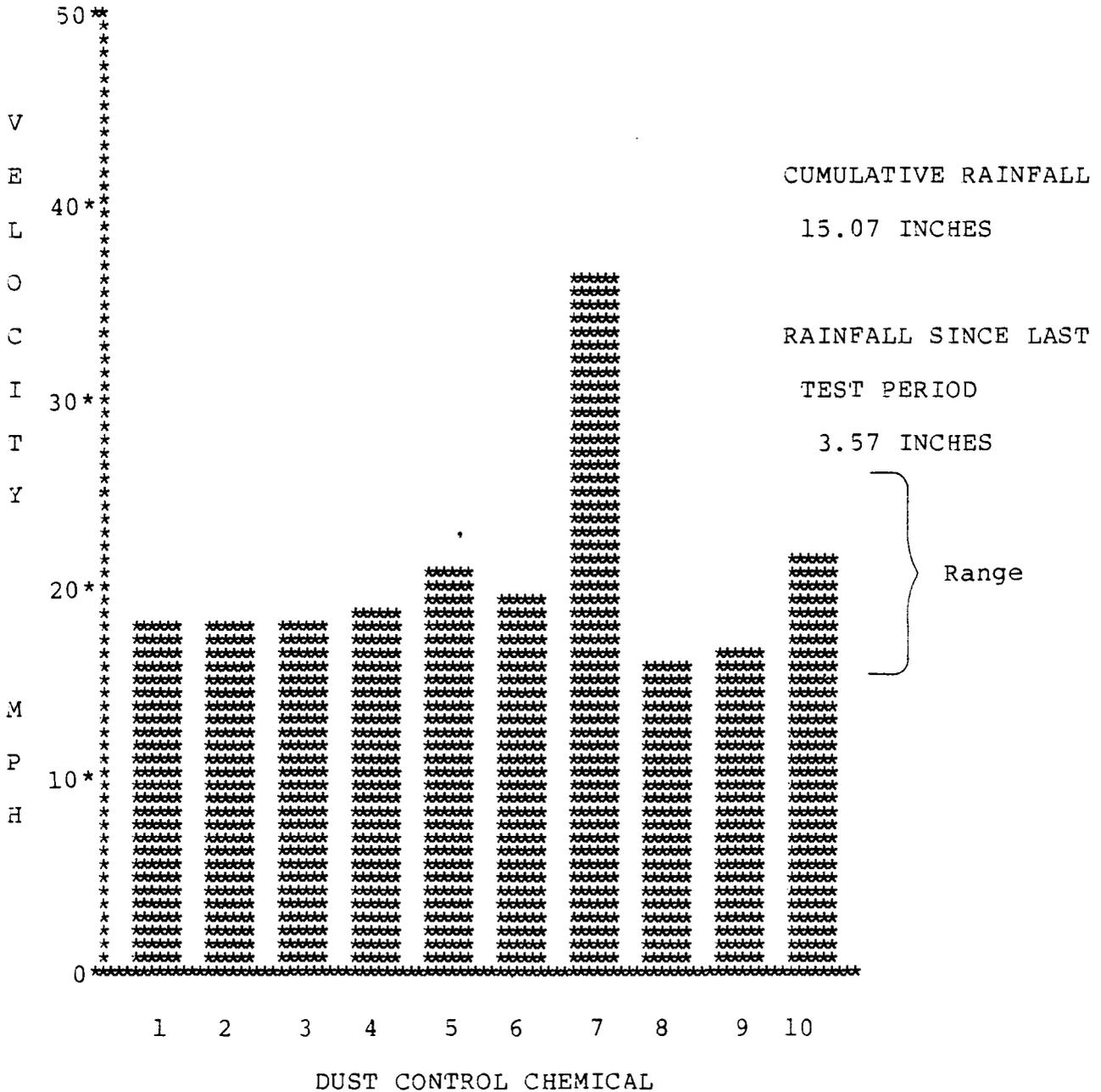
(VELOCITY @ 3 INCH HEIGHT)



- |   |                    |    |                    |             |
|---|--------------------|----|--------------------|-------------|
| 1 | Coherex 12:1       | 6  | Nalco 655          | (Tested On) |
| 2 | Coherex 9:1        | 7  | Magnesium Chloride | Wet, Wet    |
| 3 | Lignosulfonate 8:1 | 8  | Magnesium Chloride | Dry, Dry    |
| 4 | Lignosulfonate 4:1 | 9  | Magnesium Chloride | Dry, Dry    |
| 5 | Nalco 656          | 10 | Uncontrolled Mean  |             |

Figure 15.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 6 (9/21)  
 (VELOCITY @ 3 INCH HEIGHT)



- |   |                    |    |                    |             |
|---|--------------------|----|--------------------|-------------|
| 1 | Coherex 12:1       | 6  | Nalco 655          | (Tested On) |
| 2 | Coherex 9:1        | 7  | Magnesium Chloride | Wet, Wet    |
| 3 | Lignosulfonate 8:1 | 8  | Magnesium Chloride | Dry, Dry    |
| 4 | Lignosulfonate 4:1 | 9  | Magnesium Chloride | Dry, Dry    |
| 5 | Nalco 656          | 10 | Uncontrolled Mean  |             |

Figures 16 to 19 present the wind erosion threshold velocity over time for each chemical stabilizer. The time period of the evaluation was four months. These figures show the variation in threshold velocity in relation to: (a) differences in dilution strength for Coherex and lignosulfonate, (b) two chemical formulations for the Nalco products, and (c) whether the means of applying magnesium chloride had an effect on resultant threshold velocities.

Figures F1-4 in Appendix F present the same information referenced to a height of 10 meters.

For the Coherex and calcium lignosulfonate the more dilute of the two chemical dilutions showed lower threshold velocities over time. This indicates that weaker application dosages of these two chemical stabilizers will result in lower overall control effectiveness. The two Nalco products showed little variation between them over time.

The magnesium chloride displayed a different variation over time relative to the other chemical stabilizers. From the field testing it appears the magnesium chloride either "works" or "doesn't work". The chemical stabilizer attracts moisture from the tailings surface and/or atmosphere resulting in the binding together of the surface fines. When this occurs, the tailings take on a darker than normal color. Throughout the time of the field testing there was a visible gradual decay in the size of the controlled (darker) areas within both the wet and dry test plots. The decay started in the coarse (west) end of the plots and migrated to the finer sized tailings. The tailings which had lost the binding effect of the magnesium chloride took on a lighter color and had near zero control efficiency.

Figures 20 and 21 present the percentage of the tailings surface which appeared wet during the test periods. Figure 20 presents the information for the half acre test plot which was wetted (wet test plot) prior to chemical application. Figure 21 presents the information for the half acre test plot which was left dry (dry test plot) prior to chemical stabilizer application. Figure 22 summarizes the data for both test plots. It appears that wetting the test plot prior to application of the magnesium chloride is beneficial over time.

Figures 23 to 26 and Table 5 present the control effectiveness over time for the chemical stabilizers. Additionally, Table 5 presents the mean control effectiveness at two months (Periods 1-4) and four months (Periods 1-6) after application.

The control effectiveness values, in Figures 23 to 26 and Table 5, show the percent change in the wind erosion threshold velocity, for each test plot, over the period of the field testing program. Control effectiveness was calculated by assuming the tailings were at 100% control immediately after the application of the chemical stabilizers. Control effectiveness for the threshold velocities measured during subsequent field

Figure 16.

WIND EROSION THRESHOLD VELOCITY OVER TIME  
 (VELOCITY @ 3 INCH HEIGHT)

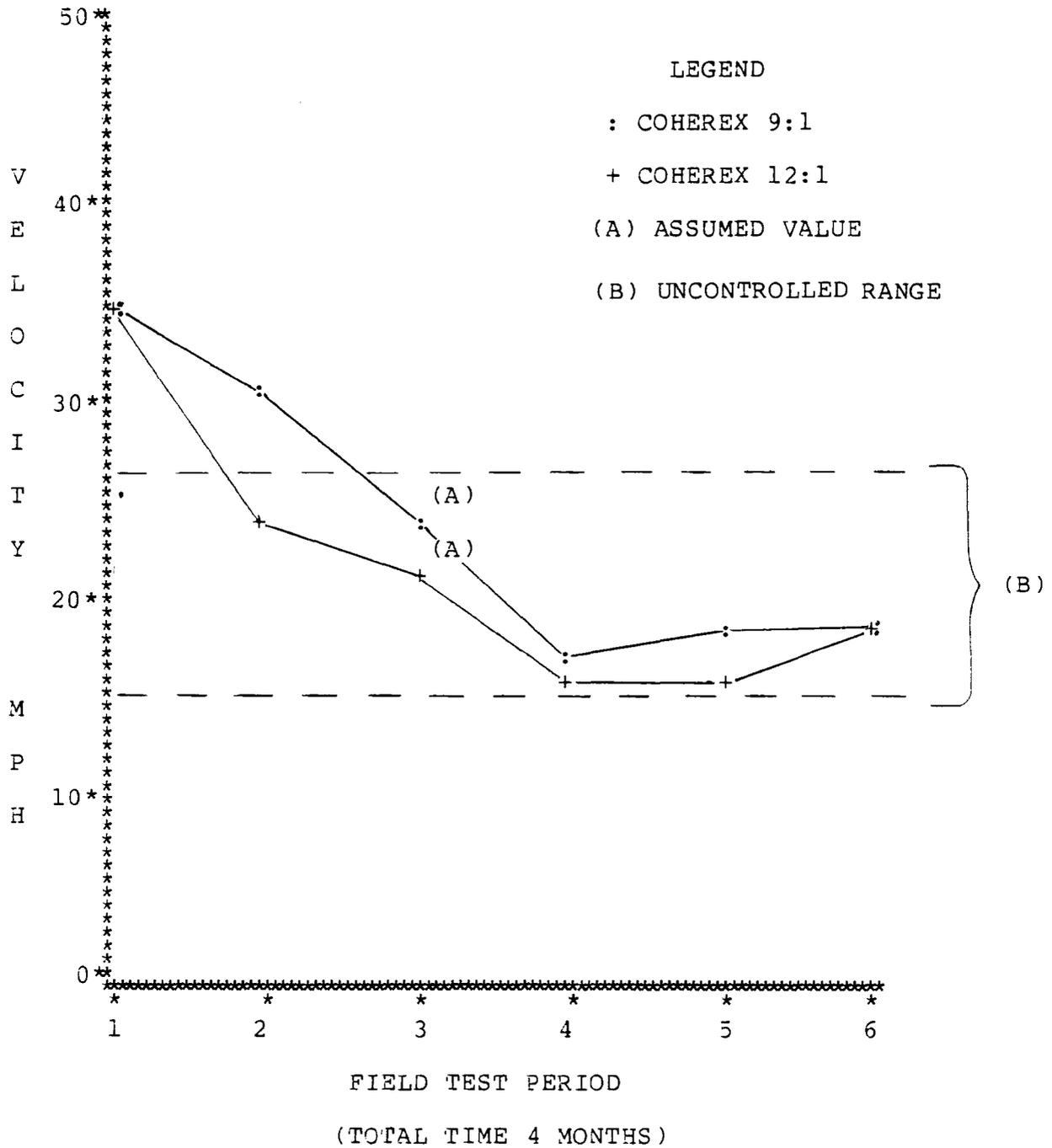


Figure 17.

LIGNOSULFONATE

WIND EROSION THRESHOLD VELOCITY OVER TIME

(VELOCITY @ 3 INCH HEIGHT)

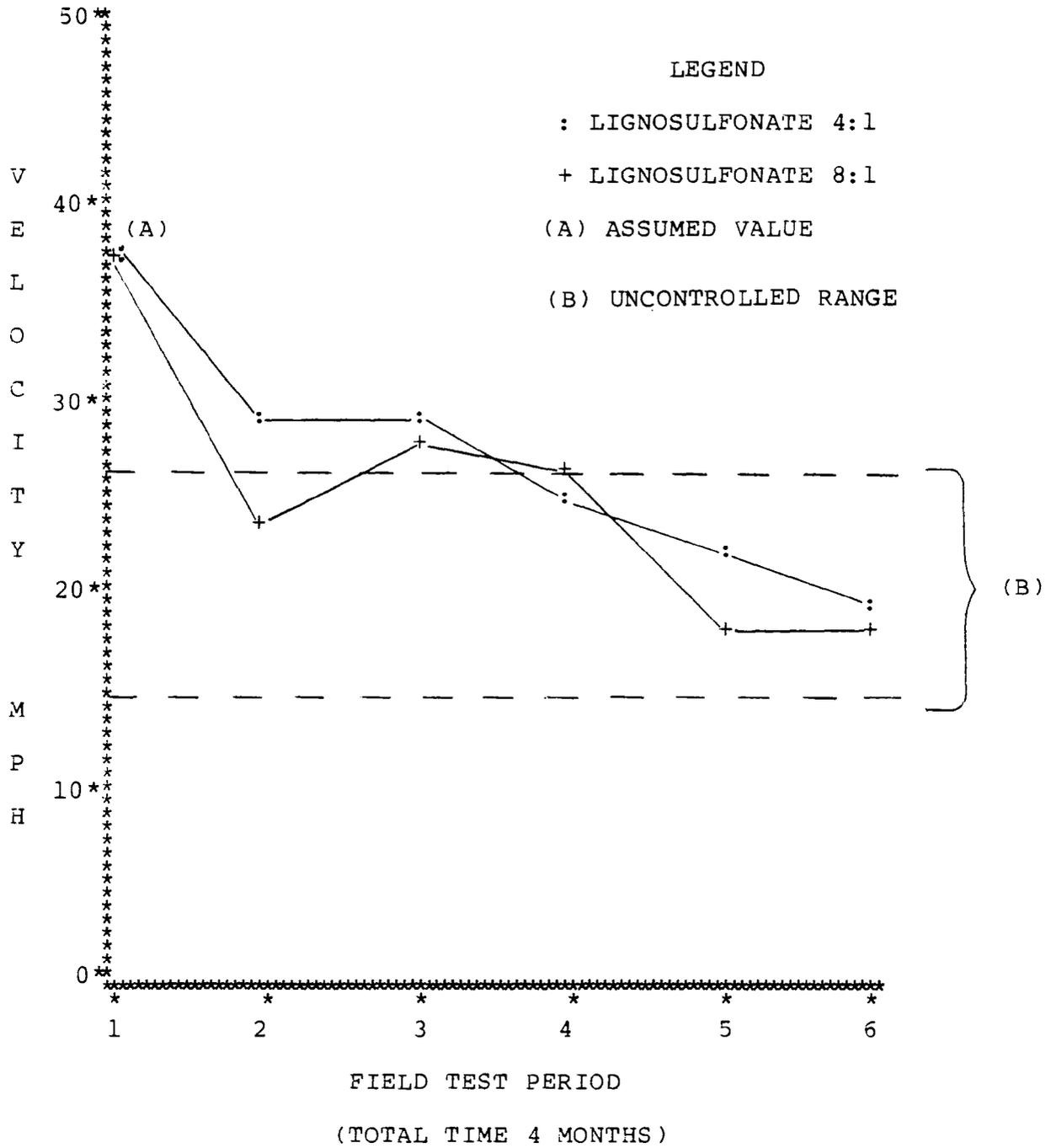


Figure 18.

NALCO 655 & 656

WIND EROSION THRESHOLD VELOCITY OVER TIME

(VELOCITY @ 3 INCH HEIGHT)

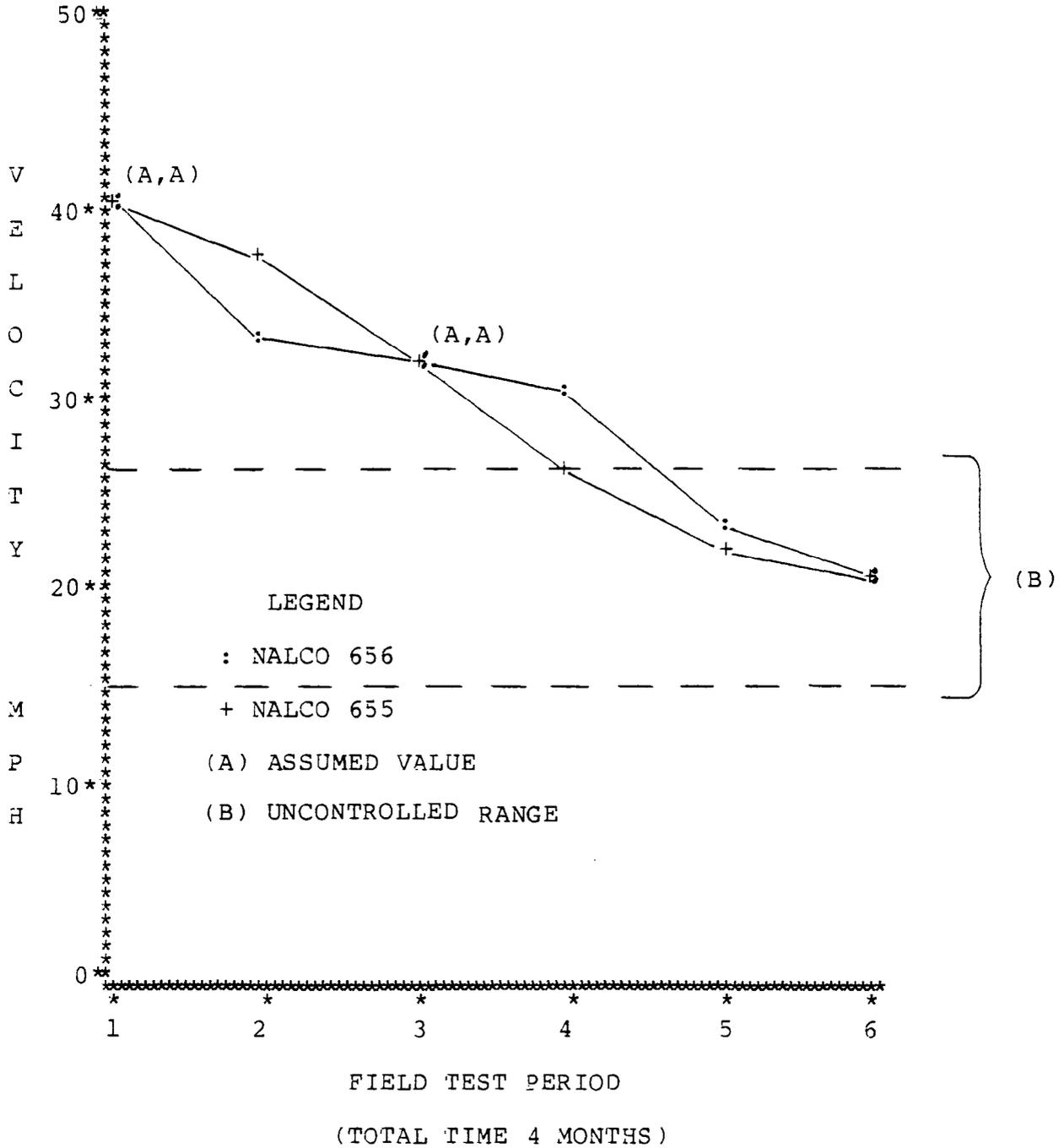


Figure 19.

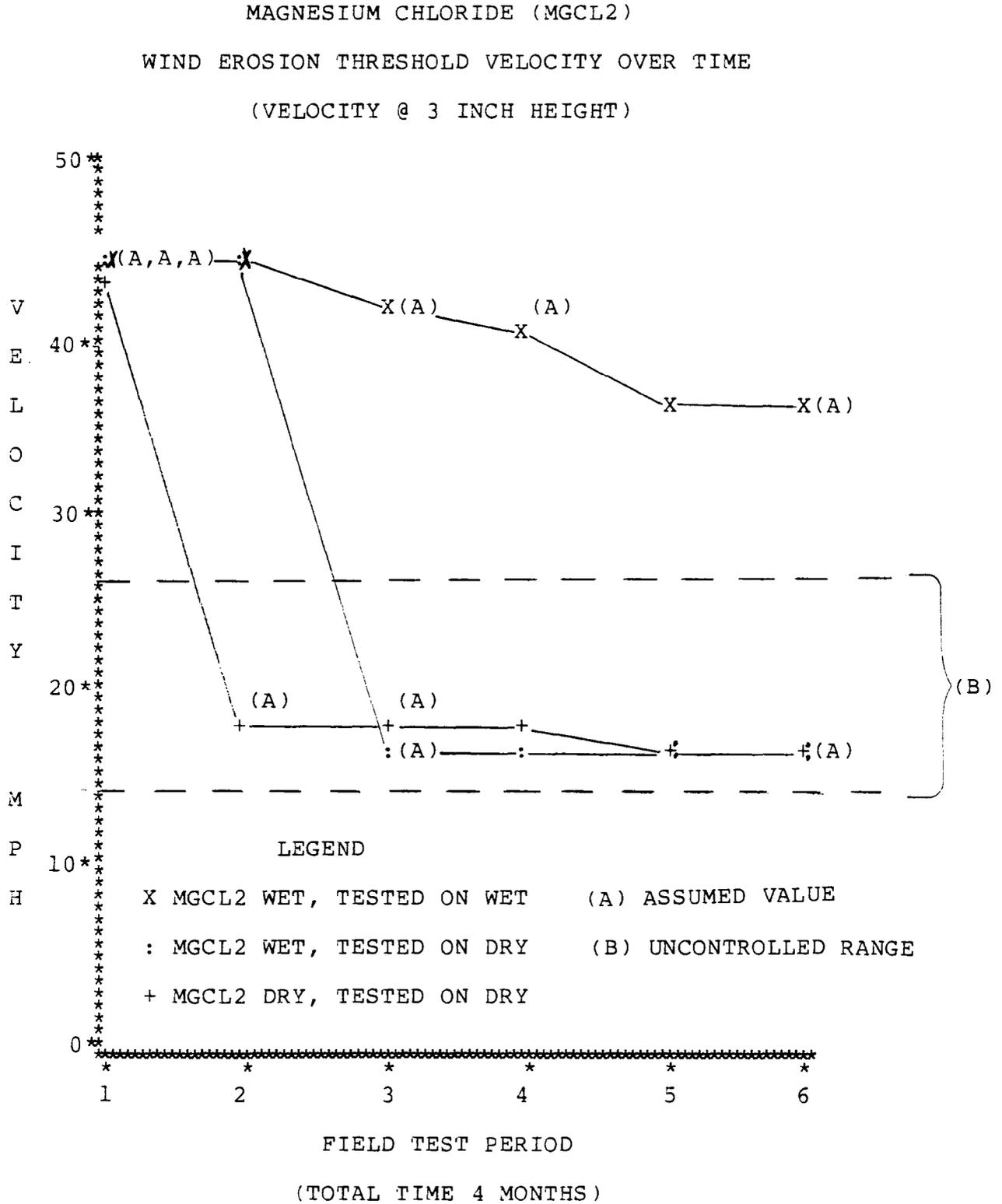


Figure 20.

MAGNESIUM CHLORIDE (MGCL<sub>2</sub>) TEST PLOT EFFECTIVENESS  
(% OF PLOT WET=FILLED AREA, % OF PLOT DRY=OPEN AREA)

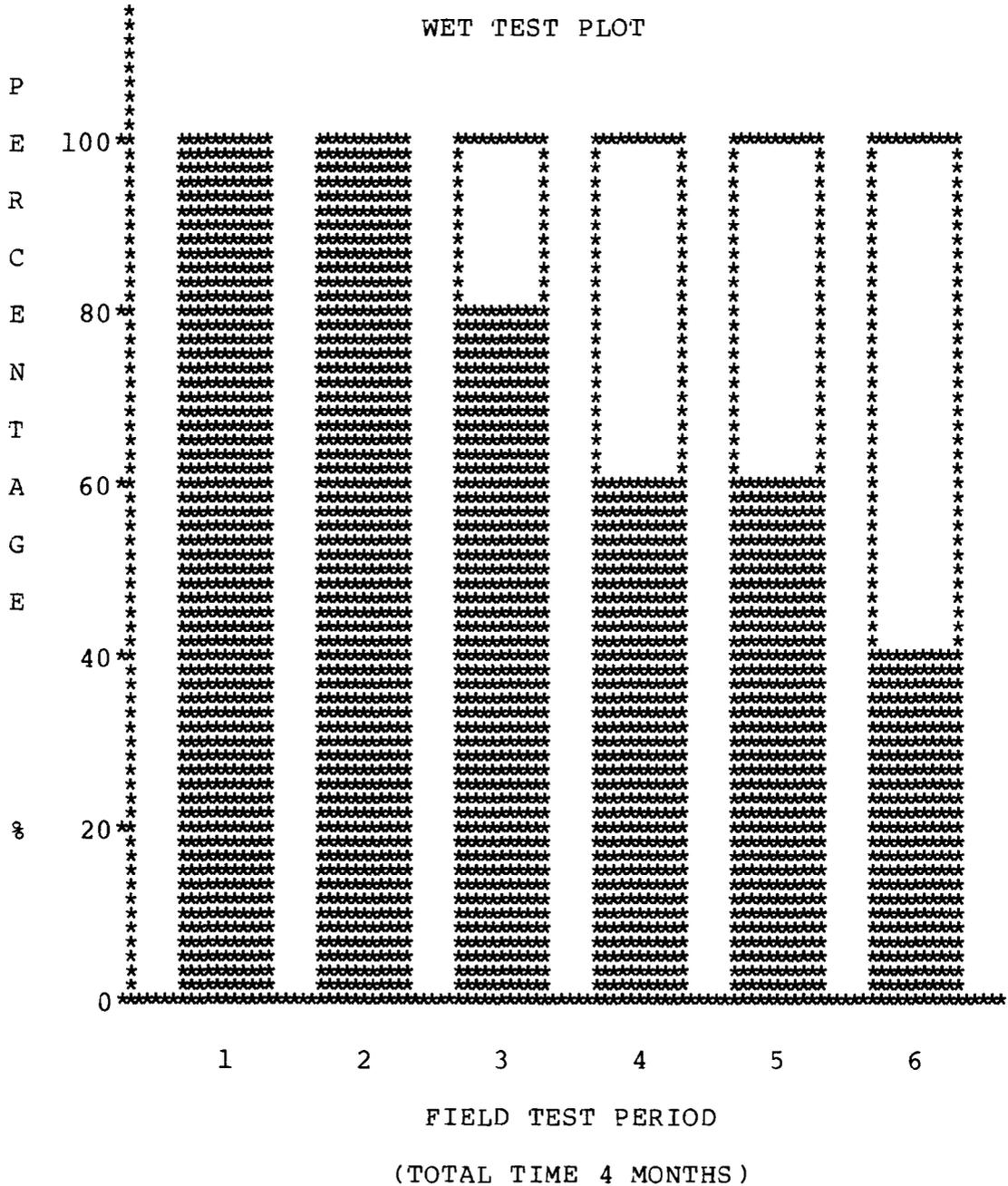


Figure 21

MAGNESIUM CHLORIDE (MGCL<sub>2</sub>) TEST PLOT EFFECTIVENESS  
(% OF PLOT WET=FILLED AREA, % OF PLOT DRY=OPEN AREA)

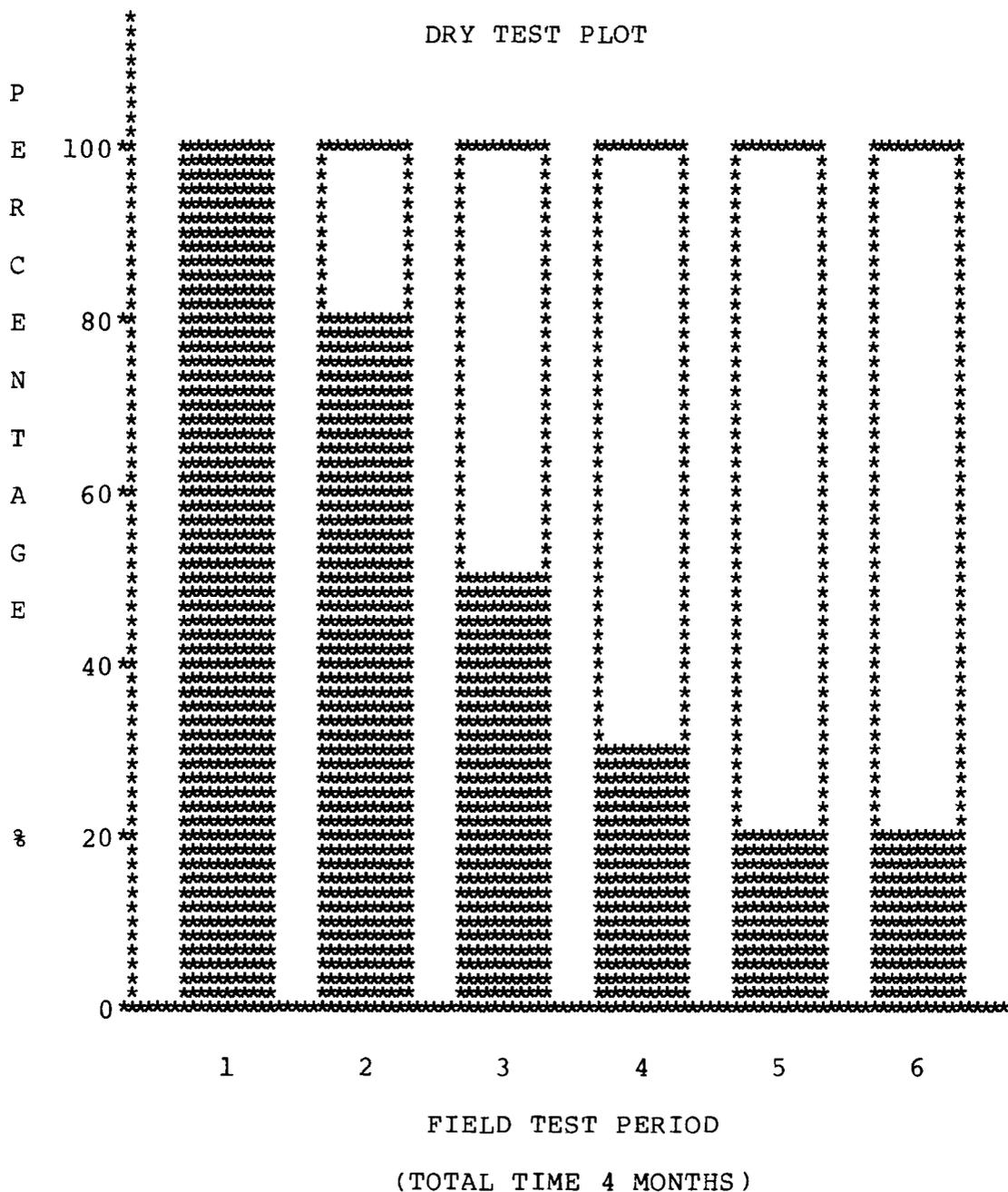


Figure 22

MAGNESIUM CHLORIDE (MGCL<sub>2</sub>) TEST PLOT EFFECTIVENESS

PERCENT OF PLOT AREA REMAINING WET

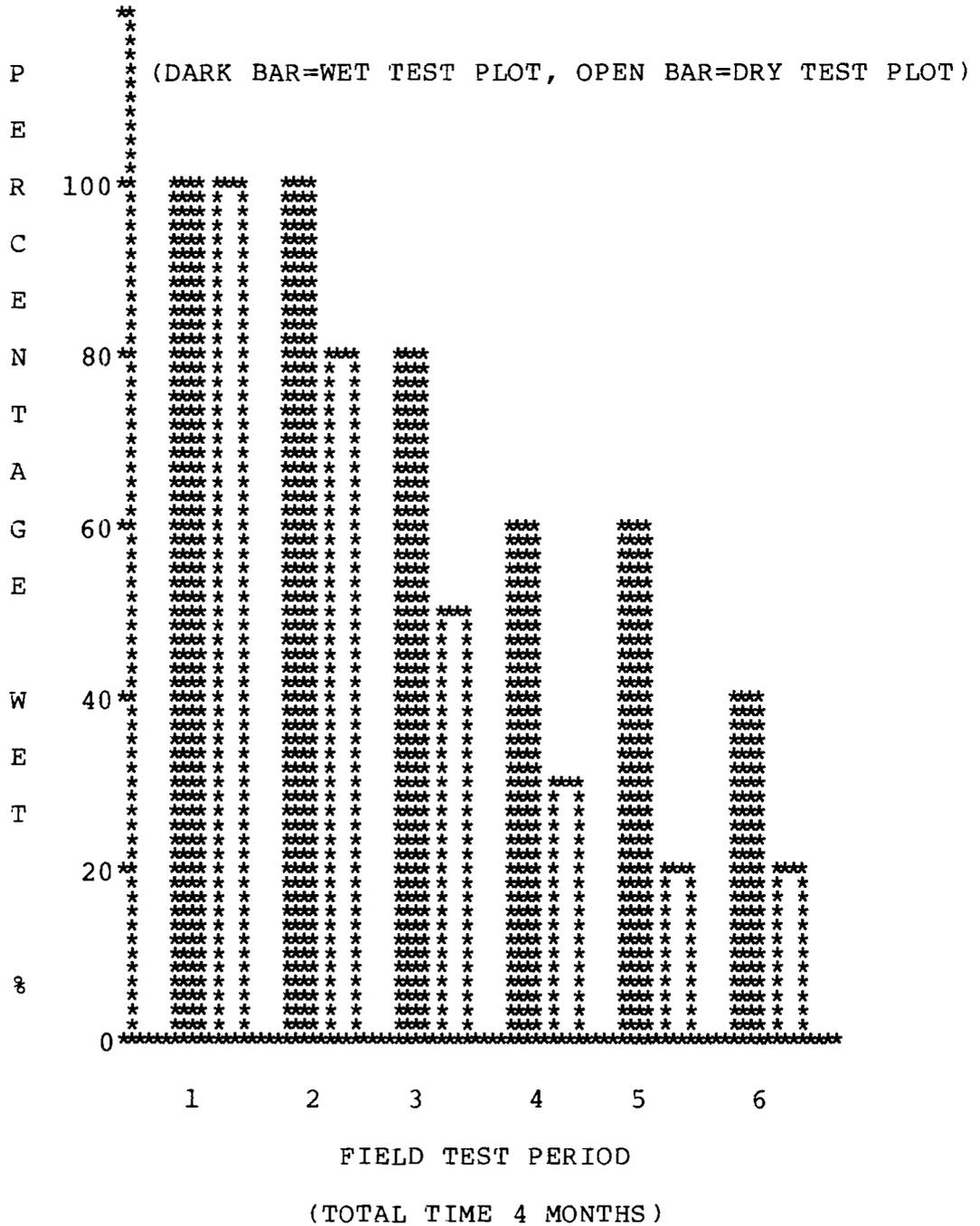


Figure 23

COHEREX  
CONTROL EFFICIENCY OVER TIME

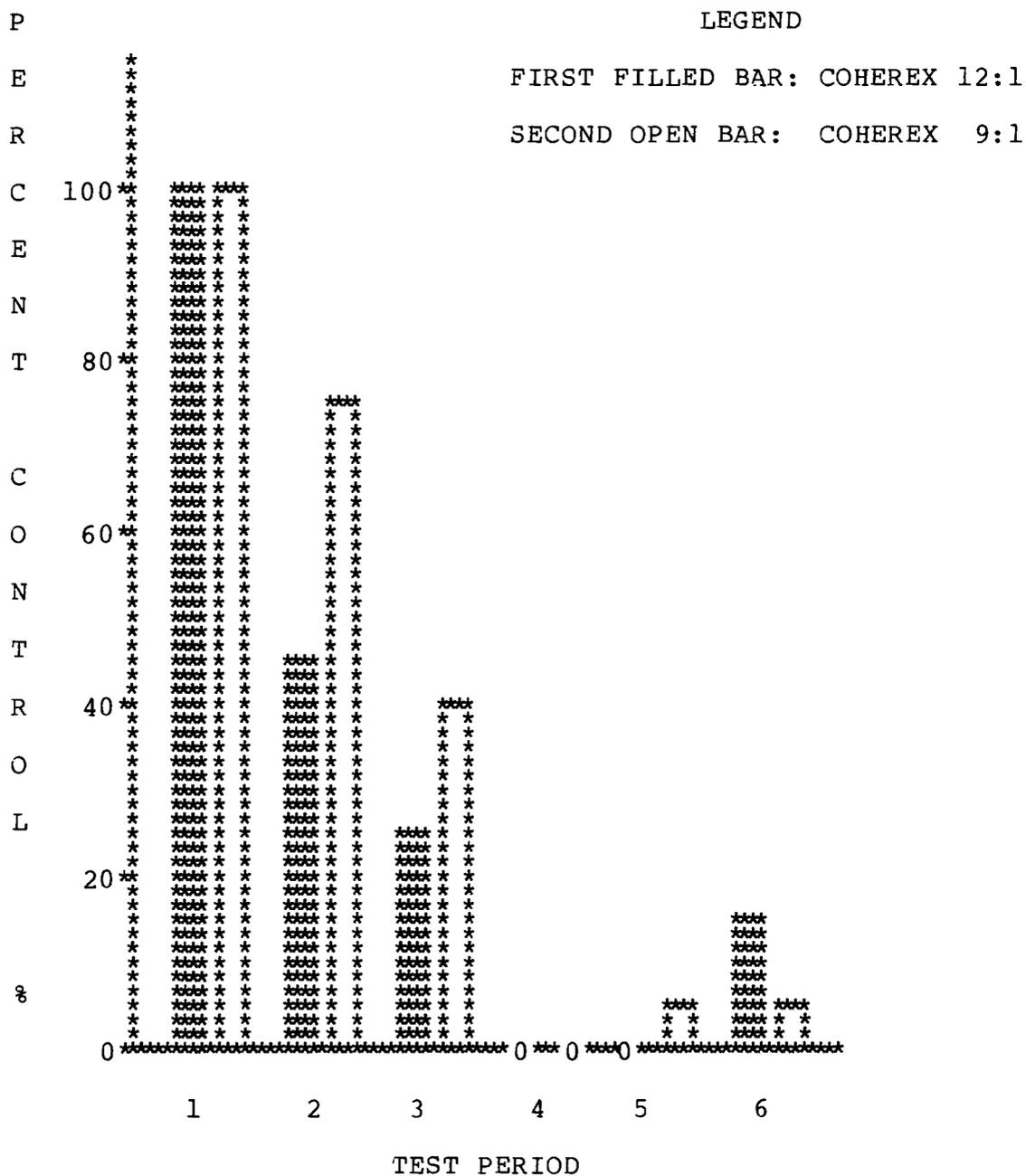


Figure 24

LIGNOSULFONATE  
CONTROL EFFICIENCY OVER TIME

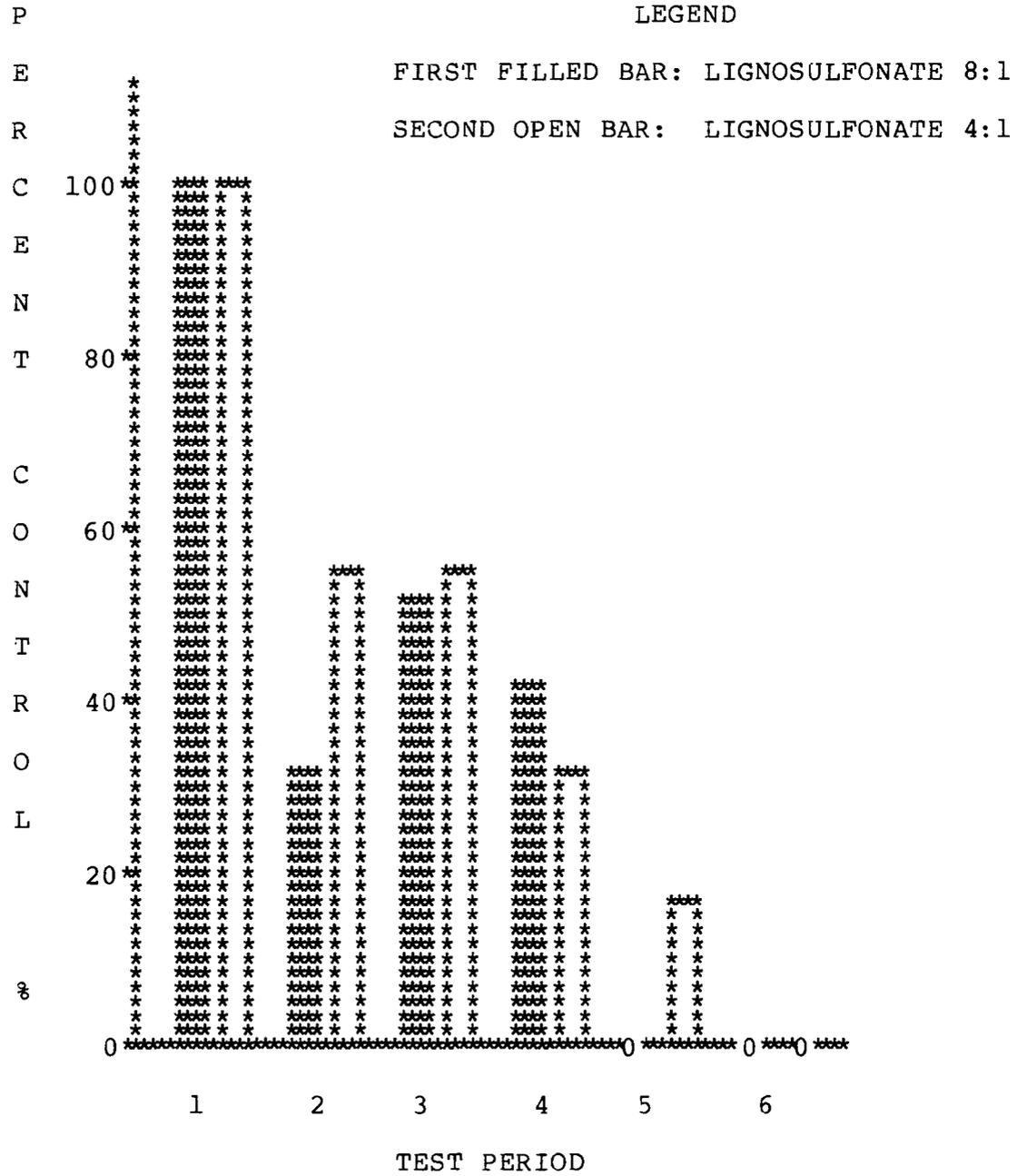


Figure 25 .

NALCO 656 & 655

CONTROL EFFICIENCY OVER TIME

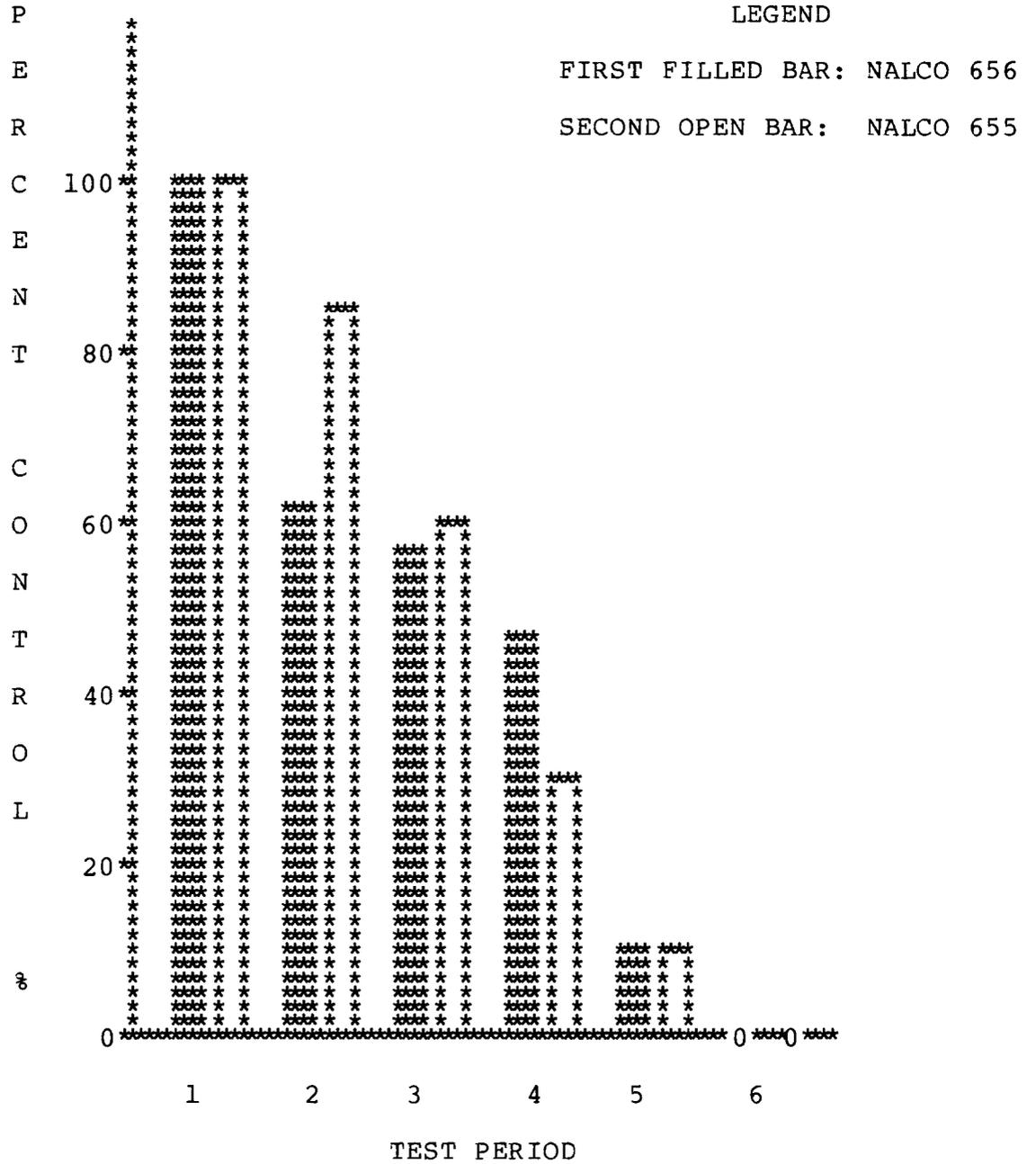
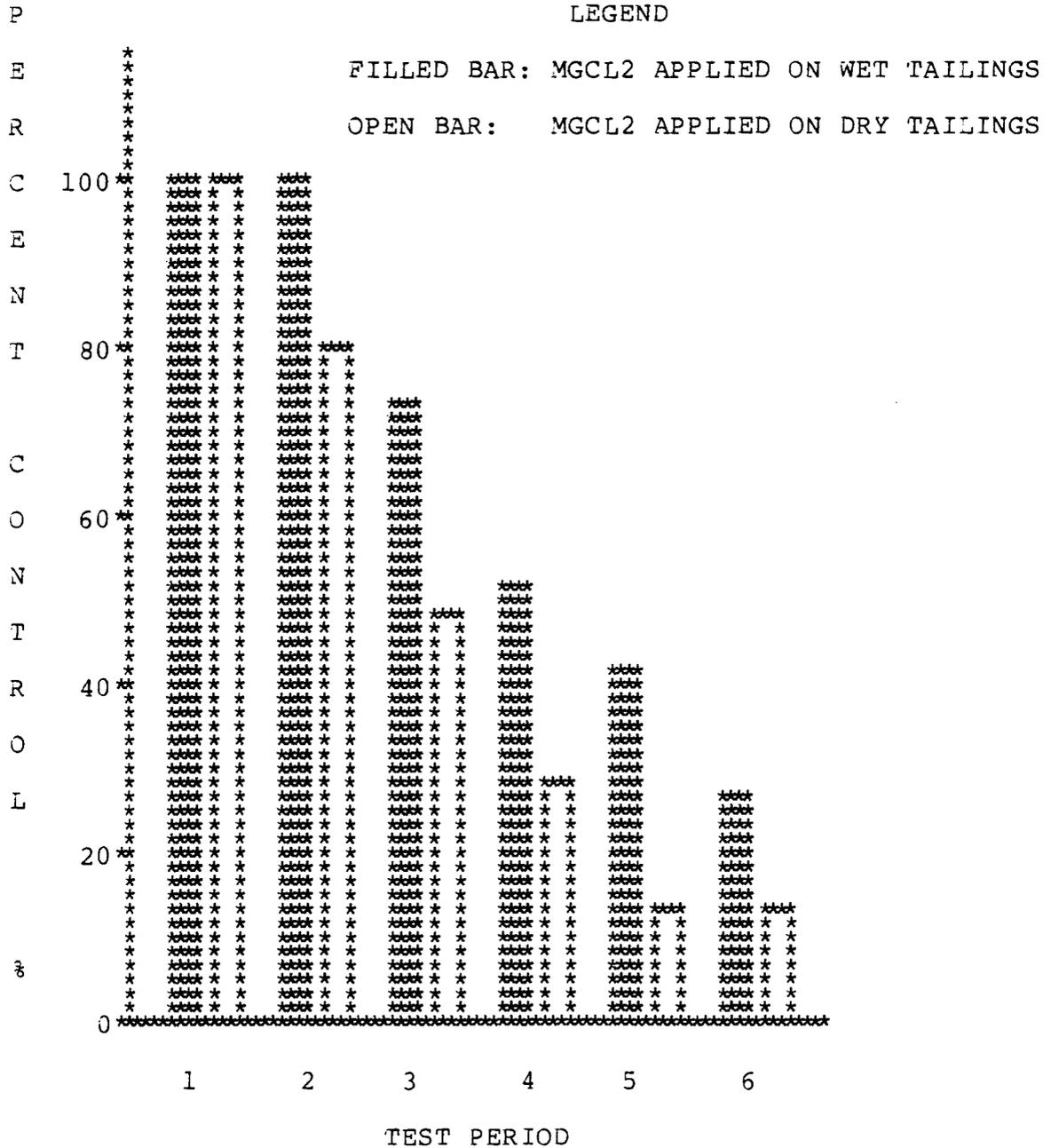


Figure 26

MAGNESIUM CHLORIDE  
CONTROL EFFICIENCY OVER TIME



test periods are calculated in the following manner. First, all threshold velocity values, for a specific chemical stabilizer, are normalized by subtracting the lowest of the measured threshold velocities for each test plot. The lowest threshold velocity, usually measured during the last test period, is assigned a control effectiveness of 0%. The lowest threshold velocity, for each chemical stabilizer, was within the range of threshold velocities measured for the untreated tailings. After the data has been normalized, the calculation used to determine control effectiveness during a test period is:

$$\text{Period X Control Effectiveness} = \frac{1 - (\text{Initial Test Period} - \text{Test Period X})}{(\text{Initial Test Period})} \times 100$$

-----

Table 5. Control Effectiveness Over Time As Determined By Threshold Velocity Testing

Test Period	Chemical Stabilizer	Control Efficiency (%)	Chemical Stabilizer	Control Efficiency (%)
1	Coherex 12:1	100	Coherex 9:1	100
2		45		76
3		25		41
4	Mean=43%	0	Mean=54%	0
5		0		6
6	Mean=31%	15	Mean=38%	6
1	Calcium	100	Calcium	100
2	lignosulfonate	32	lignosulfonate	56
3	8:1	53	4:1	56
4	Mean=57%	42	Mean=61%	33
5		0		17
6	Mean=38%	0	Mean=44%	0
1	Nalco 656	100	Nalco 655	100
2		63		85
3		58		60
4	Mean=67%	47	Mean=69%	30
5		11		10
6	Mean=47%	0	Mean=48%	0
1	Magnesium	100	Magnesium	100
2	chloride,	100	chloride,	81
3	applied onto	74	applied onto	49
4	wet tailings (a)	52	dry tailings (b)	29
5		43		14
6	Mean=66%	28	Mean=48%	14

(a) Mean control effectiveness after 2 month period = 82%

(b) Mean control effectiveness after 2 month period = 65%

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The order of the mean control effectiveness of the chemical stabilizers as determined by the threshold velocity testing is presented in Table 6.

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Table 6. Mean Chemical Stabilizer Control Effectiveness After Two And Four Months

After 2 Months		After 4 Months	
Magnesium chloride-wet	82%	Magnesium chloride-wet	66%
Nalco 655	69%	Magnesium chloride-dry	48%
Nalco 656	67%	Nalco 655	48%
Magnesium chloride-dry	65%	Nalco 656	47%
Lignosulfonate 4:1	61%	Lignosulfonate 4:1	44%
Lignosulfonate 8:1	57%	Lignosulfonate 8:1	38%
Coherex 9:1	54%	Coherex 9:1	38%
Coherex 12:1	43%	Coherex 12:1	31%

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The order of the mean chemical stabilizer control effectiveness versus time after application does not change significantly between the two time periods. Although the magnesium chloride products showed high mean effectiveness over the two and four month test periods, it should be noted that significant areas of the test plots, where the product had lost its effectiveness (as previously presented in the designated "dry" areas of Figures 20 and 21), exhibited near zero control effectiveness throughout the test periods. These areas of the test plots would erode at considerably lower wind speeds than the areas of the magnesium chloride plots which were "wet". The control effectiveness values presented for the magnesium chloride consist of a weighted average of the percent of the areas which were well controlled ("wet") and the percent of the test plot areas which exhibited virtually no control ("dry").

### 5.1.2 Wind Erosion Emission Factors

An emission factor is defined as the amount of emissions per unit of source activity. The emission factors developed in this study are reported in the form of grams/minute/square meter of tailings surface. In order to use the emission factors for emission inventorying purposes, two units of source activity are required. First, the amount of time (minutes) the wind speed is at the measured emission factor level is needed. This can be gathered from historical meteorological records. Second, the area (square meters) of tailings surface of interest in the inventory is needed. This can be determined from area maps of a tailings site.

Thirteen emission factor tests were performed during the study. Table 7 presents the results of the emission factor testing. Information presented includes, the test date, chemical name, characteristics of the tailings (moisture and silt content), the threshold velocity, the velocity at which the emission factor testing was performed, and the emission factors expressed on a particle size basis of less than 12 and 2.1 micrometers in diameter.

An example emission inventory utilising this information follows. Two areas of tailings are situated aside each other. One has been treated recently and exhibits an emission factor of 0.0162 grams/minute/square meter. The other area is a plot which has lost the bonding strength of a previously applied chemical stabilizer. It exhibits an emission factor of 1.5 grams/minute/square meter. A wind storm with gusts up to 40 mph occurs. To determine the resultant emissions less than 12 micrometers in diameter on a per acre basis, the emission factors of the two types of tailings are multiplied by the total time of the 40 mph wind gusts (assume 10 minutes), and the number of square meters in an acre (4,047). The emissions for the recently treated area are 1.4 pounds per acre, and for the uncontrolled plot the emissions are 134 pounds per acre. The difference in emissions of less than 12 micrometer diameter particles is nearly a factor of 100.

### 5.2 Meteorology

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Aside from the method of applying chemical stabilizers onto tailings, the effects of day to day meteorology are believed to have the greatest impact in determining long term control effectiveness. The following sections will characterize, over the four month testing period, the meteorological parameters believed to influence the effectiveness of chemical stabilizers.

Table 7. Wind Erosion Emission Factor Testing

Test No.	Date	Product & Dilution	Tailings (Moisture) (%)	(Silt) (%)	Threshold Velocity (10 m height-mph)	Emission Test Velocity	Factor	Results
1	5/28	Coherex 12:1	0.26	0.05	53	50	2.02	1.23
2	5/28	Coherex 9:1	0.38	0.03	53	50	2.63	1.28
3	5/28	Lignosulfonate 8:1	0.32	4.4	50	50	2.68	2.58
4	6/15	Coherex 12:1	0.46	1.6	32	40	77.2	7.16
5	6/15	Coherex 12:1	0.46	1.6	32	40	16.2	2.13
6	6/15	Coherex 9:1	0.28	4.3	46	50	0.881	0.096
7	6/15	Lignosulfonate 8:1	0.35	2.3	31	40	1.50	0.180
15	7/27	Lignosulfonate 4:1	0.28	3.3	43	50	283	54.0
16	7/27	Lignosulfonate 8:1	0.30	0.30	46	50	1,360	216
18	7/28	Nalco 655	0.10	1.30	45	50	116	18.2
19	7/28	Magnesium chloride (tested on dry section)	0.57	6.50	31	40	1,500	213
42a	9/22	Uncontrolled	0.37	0.50	40	45	73.8	17.2
43	9/22	Uncontrolled	0.35	1.0	43	50	25.6	3.10

### 5.2.1 Test Period Meteorological Characterization

Daily weather data, throughout the test period, was obtained from the Federal Aviation Administration-Flight Service Station located at the Hibbing, Minnesota Municipal Airport. The airport is located approximately ten miles east of the National Steel Pellet Co. tailings basin. The information obtained was an hourly record of precipitation, temperature, wind speed, and direction. Historical data for the Hibbing Airport was obtained from the National Climatic Center located in Ashville, North Carolina. This information was based on a 19 year average.

Table 8 presents the number of days per month in which rainfall was greater than 0.1 and 0.01 inches. Comparing the historical data (>0.1 inches) with that from 1982, July and October contained twice the number of such rain days and August and September were above the historical average.

During the field testing, it was found that 0.01 inches of precipitation was sufficient to wet the surface of the tailings, mitigating wind erosion and also stopping the testing effort, for that day. From Table 8, approximately one half of June, July, September, and October consisted of such days. No historical data was available for comparison. From this information, approximately one half of the days scheduled for possible field testing were lost due to precipitation.

Table 9 presents the monthly rainfall amounts for the time span during which testing was scheduled. July, September, and October are all above the historical average.

Table 10 presents a summary of precipitation and wind speed data between the periods of field testing. This information is useful in assessing the affect these two parameters have on chemical stabilizer effectiveness over time. Precipitation information is presented according to total rainfall per period, cumulative rainfall since the start of field testing, and the highest rainfall amount per day for each time span. This information can be used to determine the degree of leaching a chemical stabilizer may have undergone. Figure 27 presents a graphical representation of the rainfall occurring between the test periods and the cumulative rainfall over the four month field study.

The between test period wind speed information presented in Table 10 includes the mean wind speed, and the number of days having wind velocities occurring at any time greater than 20 mph. This information can be used to approximate the degree of extent which the action of high wind speeds can be attributed to the lowering of chemical stabilizer control effectiveness. The threshold velocity for untreated tailings at the field site was approximately 20 mph. For treated tailings, winds of this magnitude could begin to weaken the bonds between the fine particles, established by the chemical stabilizers.

Table 8 Number Of Days Rainfall Was Greater Than 0.1 Or 0.01 Inches

Month	Days > 0.1 Inches		Days > 0.01
	Historical Average (a)	1982	1982
June	7.3	5	13
July	6.7	13	14
August	6.9	8	10
September	5.1	8	14
October	3.8	7	17
November	3.3	(b)	(b)

(a) Historical data obtained from the National Climatic Center, Ashville, North Carolina

(b) Tailings had snow cover during the month of November

Table 9 Monthly Rainfall Totals

Month	Historical Average (a)	1982
June	4.53 Inches	2.89 Inches
July	3.91	7.86
August	4.08	1.98
September	3.05	3.50
October	2.08	4.38
November	1.77	(b)

(a) Historical data obtained from the National Climatic Center, Ashville, North Carolina

(b) Tailings had approximately 2 inches of snowcover throughout the month.

Table 10 Meteorological Summary Between Test Periods

Between Periods	Dates	Precipitation			Wind Speed	
		Rainfall (in.)	Cumulative (a) Rainfall (in.)	Highest Rainfall Per Day (in.)	Mean Wind Speed (mph)	Number Days > 20 mph (b)
1 and 2	5/29 to 6/14	1.58	1.58	1.04	10.0	5
2 and 3	6/17 to 7/7	4.62	6.2	1.35	7.6	1
3 and 4	7/9 to 7/26	4.11	10.3	0.87	6.5	0
4 and 5	8/1 to 8/16	1.23	11.5	0.76	6.2	0
5 and 6	8/19 to 9/20	3.57	15.07 (c)	1.61	6.5	0

(a) Assuming 0.0 cumulative as of 5/28/82

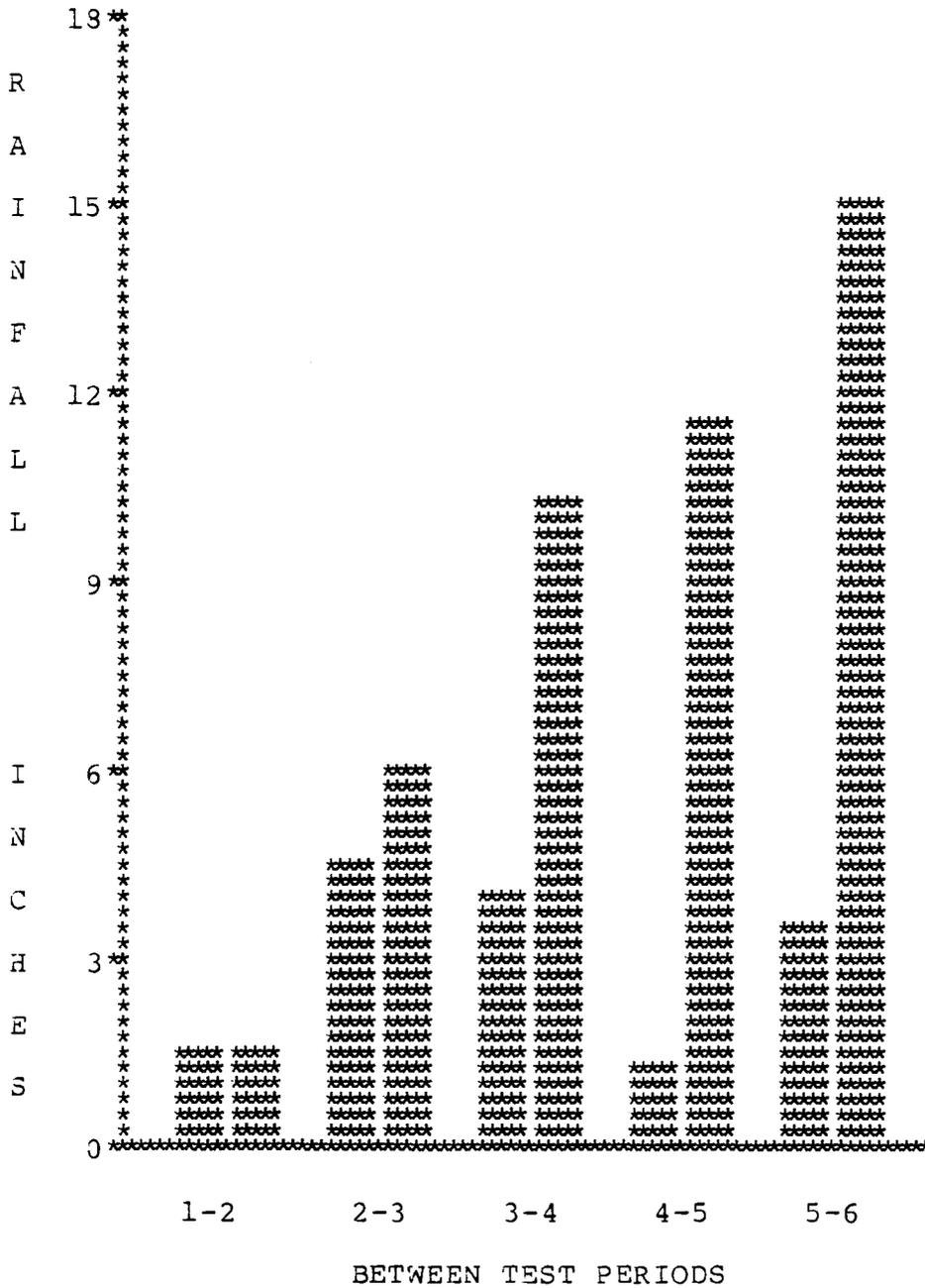
(b) Days when wind speed for any reported period was > 20 mph

(c) Total rainfall from 5/28 to 9/22 was 15.6 inches

This includes 0.53 inches on 7/29/82, which occurred between test days

Figure 27

RAINFALL AMOUNTS BETWEEN TEST PERIODS



NOTE: FIRST BAR IS RAINFALL AMOUNT BETWEEN TEST PERIODS

SECOND BAR IS CUMULATIVE RAINFALL

### 5.2.2 The Effect Of Meteorological Parameters On Dust Control Effectiveness

Based on the summary of the meteorological parameters between the field test periods presented in Table 10, it is believed that precipitation had a greater effect than wind speed, over the four month time span, in reducing the control efficiencies of the chemical stabilizers. This is due to the more than 15 inches of rainfall which occurred during the test period relative to only 6 days when wind speeds were greater than 20 mph.

Figures 28 to 31 present the effect rainfall exhibits on threshold velocity. The threshold velocities presented are those measured within the wind tunnel at a height of 3 inches. Appendix G presents the data according to an extrapolated threshold velocity height of 10 meters.

The greatest percent change in threshold velocity for Coherex 12:1, Lignosulfonate 8:1 and 4:1, and the Magnesium Chloride applied dry and tested on the dry portion of the test plot, occurred between test periods 1 and 2. This time period was characterized by a total of 1.58 inches of rainfall, 1.04 inches of rainfall occurring on one day, and 5 days when the wind speed exceeded 20 mph at any time during the day. The lignosulfonate, as reported by plant personnel using the product, can be leached with rainfall amounts greater than 0.5 inches. This combined with the high wind speeds probably attributed to its enhanced decay.

The Coherex 12:1 and Magnesium Chloride-Dry (applied dry onto the tailings and tested on the dry-uncontrolled areas), were applied onto the tailings at alternate (lesser) dosage levels than recommended. Thus, the bonding strength these chemicals produced could not resist the effects of the rainfall and high wind speeds which occurred soon after application.

The Coherex 9:1, Nalco 655, and the Magnesium Chloride-Wet (applied onto wet tailings and tested on the dry-uncontrolled areas), had their greatest percent decay rates between test periods 3 and 4. This period is characterized by a rainfall amount of 4.1 inches and a cumulative rainfall amount of 10.3 inches. Daily ambient wind speed had not exceeded 20 mph since between test periods 1 and 2, (5 days) and between test periods 2 and 3, (1 day). Thus, the cumulative effect of rainfall is believed to have been the major reason for the reduction in control efficiency at this time.

The Nalco 656 and Magnesium Chloride-Wet (applied onto wet tailings and tested on the wet-controlled areas), had their greatest percent decay rates of threshold velocity between test

Figure 28.

COHEREX  
 EFFECT OF RAINFALL ON THRESHOLD VELOCITY  
 (VELOCITY @ 3 INCH HEIGHT)

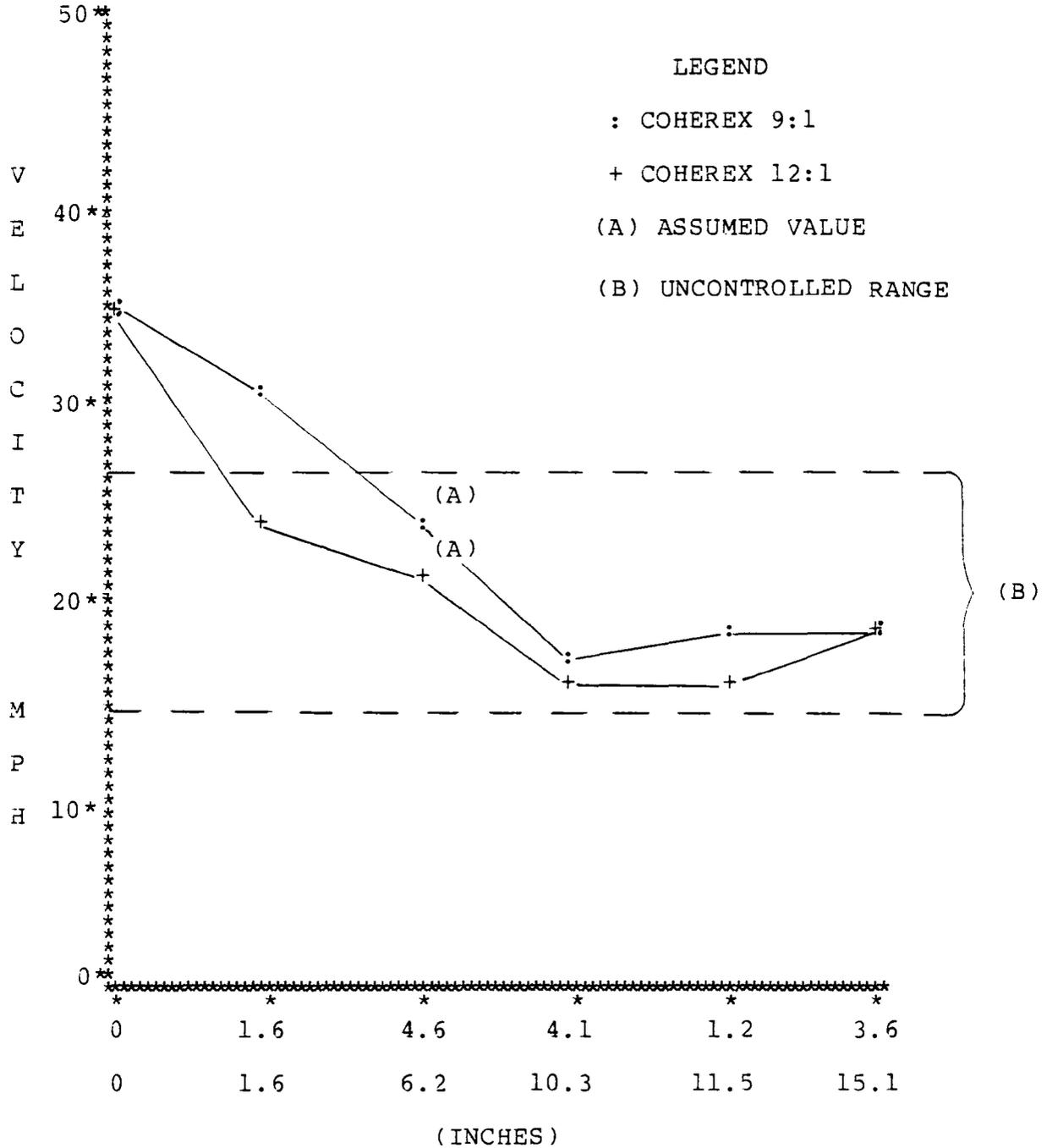
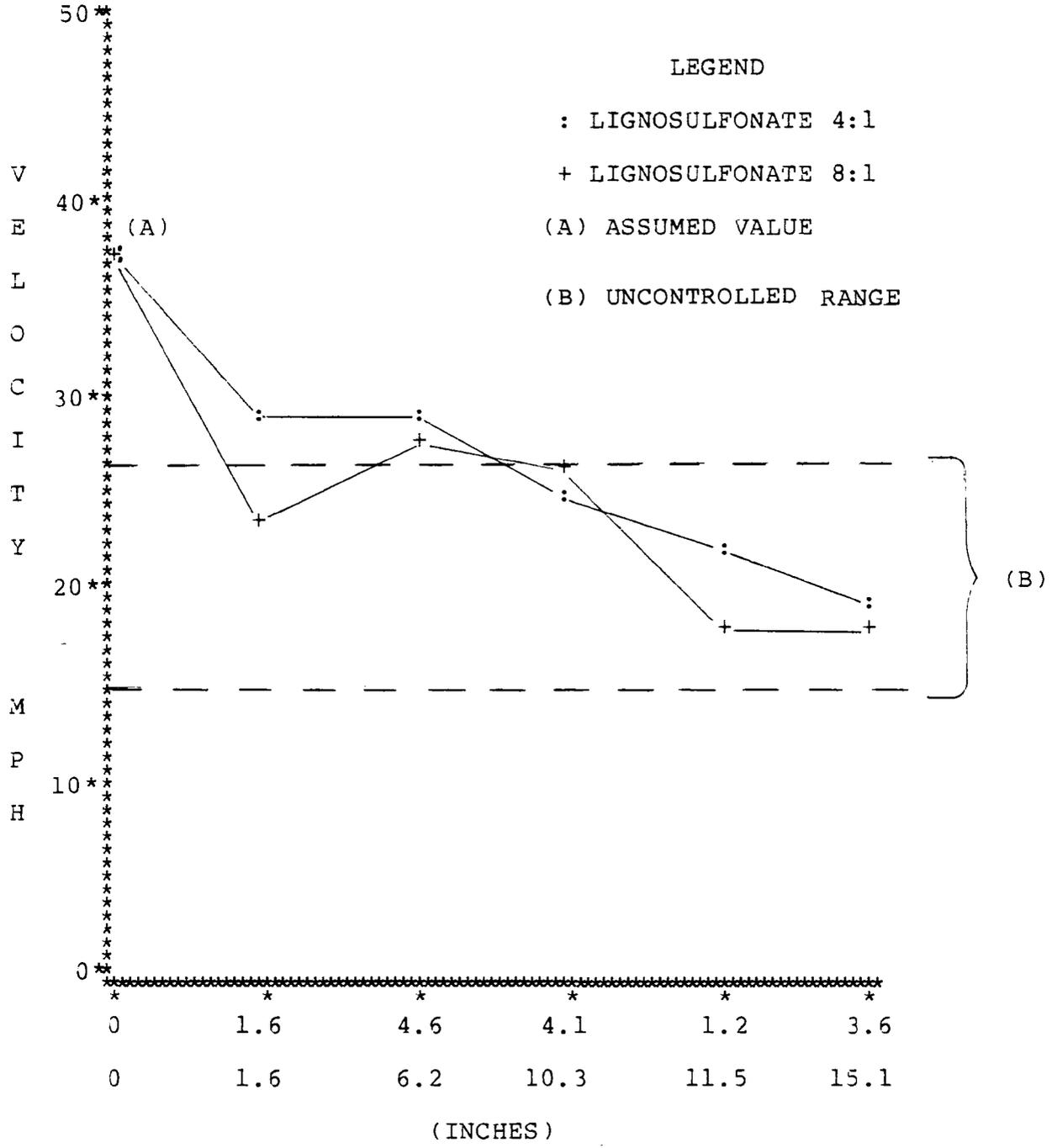


Figure 29.

LIGNOSULFONATE  
 EFFECT OF RAINFALL ON THRESHOLD VELOCITY  
 (VELOCITY @ 3 INCH HEIGHT)



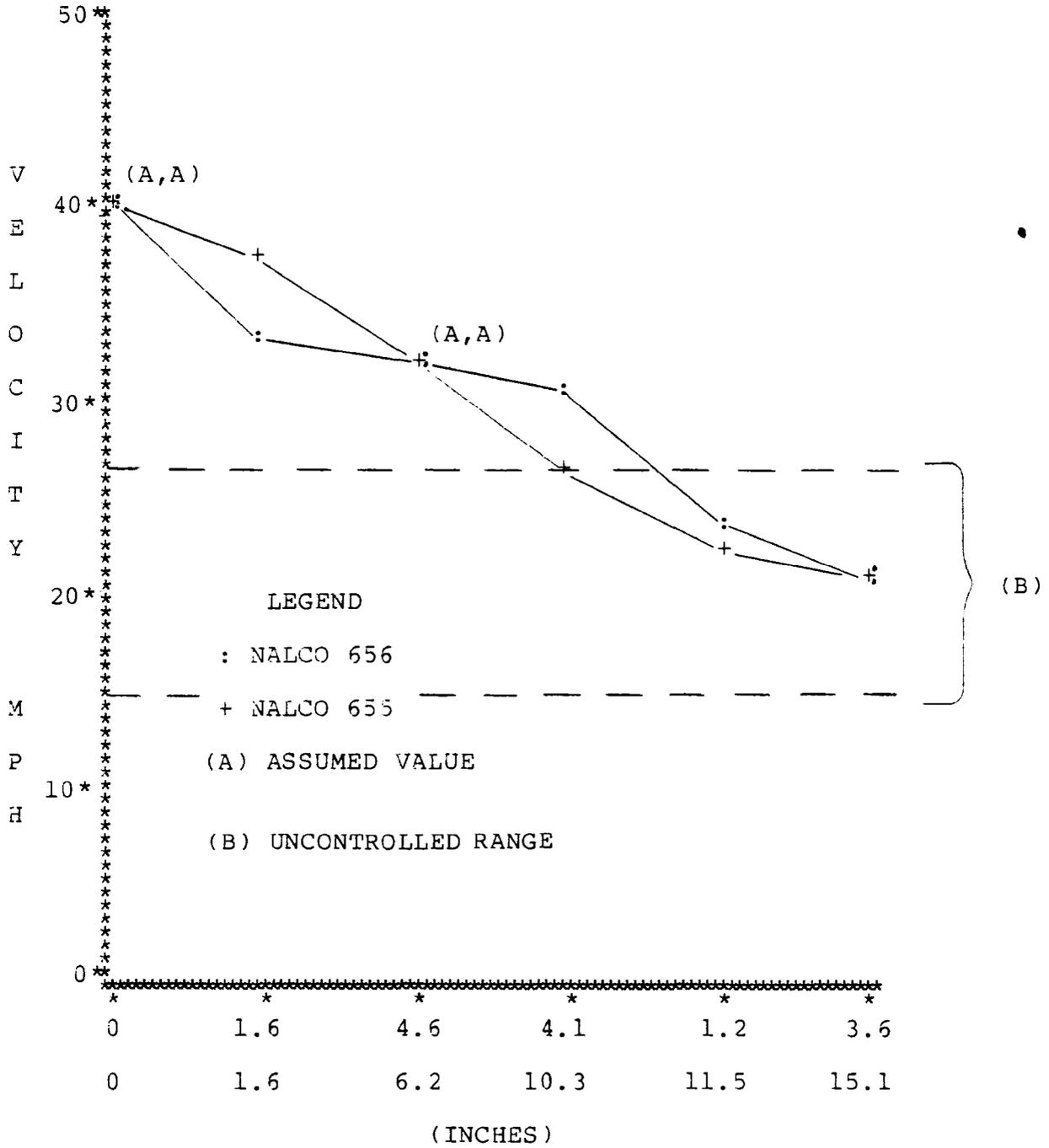
FIRST ROW: RAINFALL SINCE PREVIOUS TEST PERIOD  
 SECOND ROW: CUMULATIVE RAINFALL

Figure 30.

NALCO 655 & 656

EFFECT OF RAINFALL ON THRESHOLD VELOCITY

(VELOCITY @ 3 INCH HEIGHT)

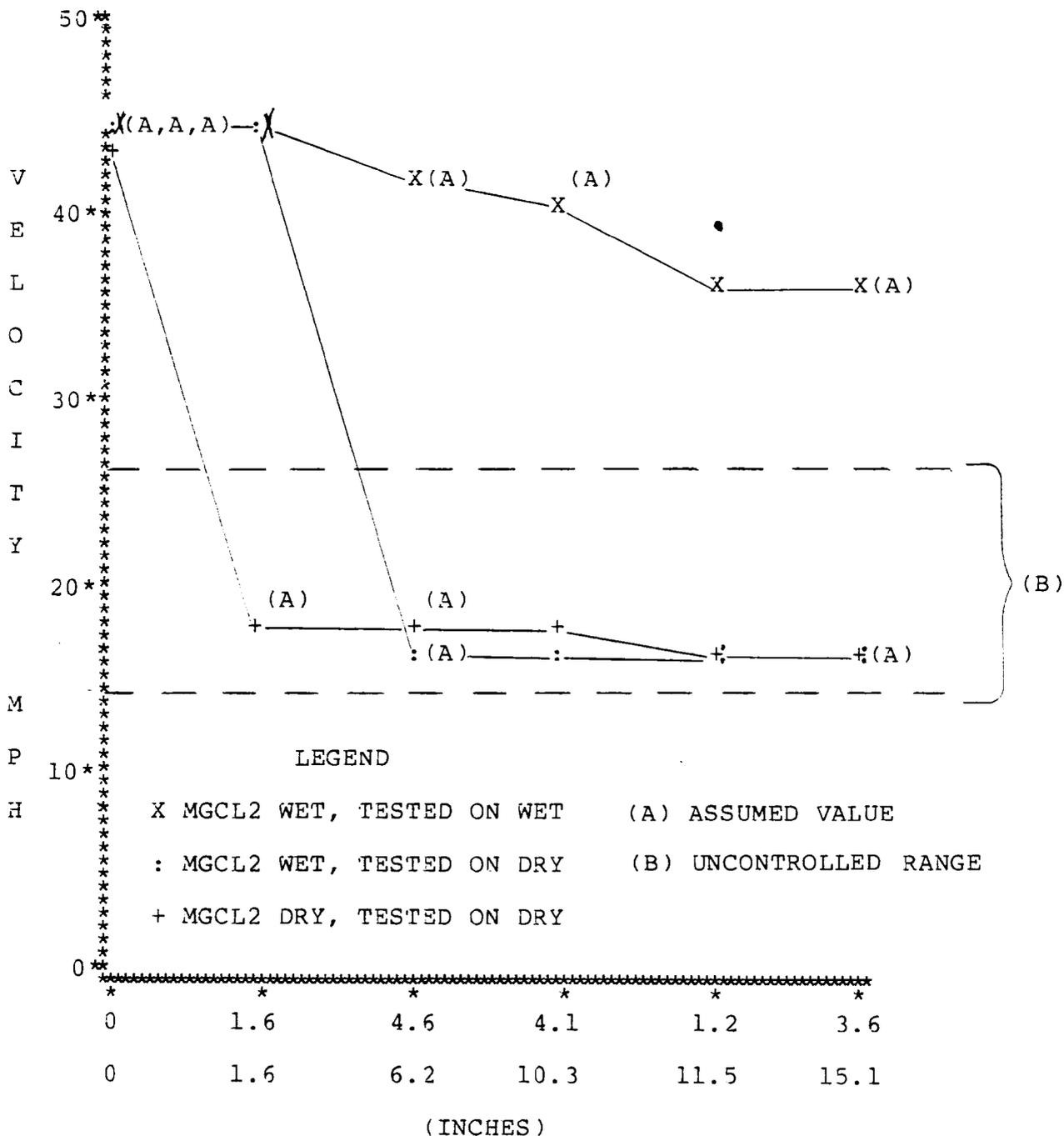


FIRST ROW: RAINFALL SINCE PREVIOUS TEST PERIOD

SECOND ROW: CUMULATIVE RAINFALL

Figure 31.

MAGNESIUM CHLORIDE (MGCL2)  
 EFFECT OF RAINFALL ON THRESHOLD VELOCITY  
 (VELOCITY @ 3 INCH HEIGHT)



FIRST ROW: RAINFALL SINCE PREVIOUS TEST PERIOD  
 SECOND ROW: CUMULATIVE RAINFALL

periods 4 and 5. This period is characterized by a rainfall amount of 1.2 inches and a cumulative rainfall amount of 11.5 inches. Ambient winds speeds exceeding 20 mph had not occurred in the last two periods. Thus, the cumulative effect of rainfall is believed to have been the major reason for the reduction in control efficiency at this time.

As previously presented, aside from the time span between test periods 1 and 2, when days with high wind speeds were prevalent, the meteorological factor in this study believed to have the most effect on chemical stabilizer control efficiency over time was rainfall. Rainfall, coupled with days of high wind speeds (>20 mph), probably produces a synergistic effect and acts to accelerate the decay in threshold velocity, as was evident in the decay rates of Coherex 12:1, lignosulfonate 8:1 and 4:1, and the magnesium chloride-dry products.

### 5.3 Tailings Characteristics

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Prior to applying the chemical stabilizers onto the tailings, surface samples were obtained for moisture and silt content analysis. This initial silt content or fines content of the tailings is presented in Section 4.3.3., Figure 9.

Since the application of chemical stabilizers bonds together the silt sized particles, it is expected that samples taken at incremental periods after initial chemical application should be much lower in apparent silt content. After initial application, the abundance of fines is minimal, requiring high ambient winds speeds (threshold velocities > 50 mph) to move the larger bonded particles. As these bonds weaken over time, the silt fraction of the tailings surface increases. This increase in fines results in the lowering of the wind erosion threshold velocity.

Table 11 presents the results of the tailings silt and moisture analyses performed throughout the study. The threshold velocities associated with each collected sample are also presented. Table 12 presents the tailings characteristics of moisture and silt content over time by chemical stabilizer. The table also includes the threshold velocities associated with the tailings. Figure 32 presents the specific test plot locations of the samples collected as reported in Table 11.

Tables 11 and 12 show the moisture content of the tailings had small variations throughout the study. Since the field testing required testing on dry tailings, this was expected. The moisture content data does show that aside from the magnesium chloride, the other chemical stabilizers do not rely on moisture content as their bonding agent. This is evident from the range of the measured moisture contents which varied from less than 0.1% to 0.6%. This was within the range of the moisture contents measured for the uncontrolled tailings, 0.12 to 1.1%.

Table 11 Tailings Moisture & Silt Content/Threshold Velocity

Test No.	Date	Product/ Dilution	Moisture (%)	Silt (%)	Threshold Velocity (mph) 3 in. (a) 10 m
1	5/28	Coherex 12:1	0.26	0.05	35
2	5/28	Coherex 9:1	0.38	0.03	34
3	5/28	Lig. Sul. 8:1	0.30	4.40	37
4&5	6/15	Coherex 12:1	0.46	1.60	24
6	6/15	Coherex 9:1	0.28	4.30	30
7	6/15	Lig. Sul. 8:1	0.35	2.30	24
8	6/15	Lig. Sul. 4:1	0.40	4.50	29
9	6/16	Nalco 656	0.39	3.40	33
10	6/16	Nalco 655	0.56	2.70	37
11	6/16	Mg Cl2 Dry	1.90	0.0	43
12	6/16	Mg Cl2 Wet	3.30	0.0	44
13	7/8	Lig. Sul. 8:1	0.34	2.05	28
14	7/8	Lig. Sul. 4:1	0.09	2.60	29
15	7/27	Lig. Sul. 4:1	0.28	3.30	25
16	7/27	Lig. Sul. 8:1	0.30	0.30	26
17	7/28	Nalco 656	0.37	2.10	30
18	7/28	Nalco 655	0.10	1.30	26
19	7/28	Mg Cl2 Dry	0.57	6.50	18
20	7/28	Mg Cl2 Wet	3.0 (b)	6.5 (b)	17
21	7/31	Coherex 9:1	0.43	12.7	17
22	7/31	Coherex 12:1	0.38	0.43	15
23	7/31	Uncontrolled	0.46	8.3	23
24	8/17	Uncontrolled	0.19	1.9	24
25	8/17	Uncontrolled	0.12	0.26	19
26	8/17	Uncontrolled	0.23	14.7	15
27	8/17	Nalco 656	0.12	2.7	23
28	8/17	Nalco 655	0.08	9.9	22
29	8/17	Lig. Sul. 4:1	0.16	3.5	22
30	8/17	Lig. Sul. 8:1	0.13	7.8	18

Table 11 Con't. Tailings Moisture  
& Silt Content/Threshold Velocity

31	8/17	Coherex 9:1	0.26	13.0	18	33
32	8/17	Coherex 12:1	0.26	11.6	15	28
33	8/18	Mg Cl2 Dry	0.33	5.8	17	35
34	8/18	Mg Cl2 Wet	0.61	11.1	16	28
35	8/18	Mg Cl2 Wet	3.4	3.6	36	80
36	9/21	Coherex 12:1	0.26	9.3	18	31
37	9/21	Coherex 9:1	0.36	4.6	18	26
38	9/21	Lig. Sul. 8:1	0.26	2.9	18	31
39	9/21	Lig. Sul. 4:1	0.55	2.2	19	30
40	9/21	Nalco 656	0.40	3.0	21	35
41	9/21	Nalco 655	0.30	6.9	20	31
42	9/21	Mg Cl2 Dry	0.20 (b)	10.0 (b)	17	32
42a	9/22	Uncontrolled	1.05	0.80	26	40
43	9/22	Uncontrolled	0.37	0.50	22	43
44	9/22	Uncontrolled	0.35	1.0	24	40
45	9/22	Uncontrolled	0.27	2.1	23	44

(a) Height of measurement, 3 inches is the midpoint height of the wind tunnel, 10 meters is the 3 inch height velocity extrapolated to a height of 10 meters

(b) Estimated value, based on similiar conditions of other test runs

Table 12 Tailings Characteristics Over Time By Chemical Stabilizer

Product	Date	Threshold Velocities		Moisture (%)	Silt (%)
		3 in. (a)	10 m		
Coherex 12:1	5/28	35	53	0.26	0.05
	6/15	24	32	0.46	1.6
	7/8	20 (b)	28 (b)	(c)	(c)
	7/31	15	23	0.38	0.43
	8/17	15	28	0.26	11.6
	9/21	18	31	0.26	9.3
Coherex 9:1	5/28	34	53	0.38	0.03
	6/15	30	46	0.28	4.3
	7/8	24 (b)	36	(c)	(c)
	7/31	17	26	0.43	12.7
	8/17	18	33	0.26	13.0
	9/21	18	26	0.36	4.6
Lignosulfonate 8:1	5/28	37	80	0.30	4.4
	6/15	24	31	0.35	2.3
	7/8	28	49	0.34	2.1
	7/27	26	46	0.30	0.30
	8/17	18	31	0.13	7.8
	9/21	18	31	0.26	2.9
Lignosulfonate 4:1	5/28	37 (b)	50 (b)	(c)	(c)
	6/15	29	41	0.39	4.5
	7/8	29	47	0.09	2.6
	7/27	25	43	0.30	3.3
	8/17	22	38	0.16	3.5
	9/21	19	30	0.55	2.2
Nalco 656	5/28	40 (b)	60 (b)	(c)	(c)
	6/16	33	55	0.34	3.4
	7/8	32 (b)	55 (b)	(c)	(c)
	7/28	30	55	0.40	2.1
	8/17	23	42	0.12	2.7
	9/21	21	35	0.40	3.0
Nalco 655	5/28	40 (b)	70 (b)	(c)	(c)
	6/16	37	66	0.56	2.7
	7/8	32 (b)	56 (b)	(c)	(c)
	7/28	26	45	0.10	1.3
	8/17	22	44	0.08	9.9
	9/21	20	31	0.30	6.9
Magnesium Chloride (Applied on wet tailings, tested on the wet areas)	5/28	44 (b)	80 (b)	(c)	(c)
	6/16	44	80	3.3	0.0
	7/8	42 (b)	80 (b)	(c)	(c)
	7/28	40 (b)	80 (b)	(c)	(c)
	8/18	36	80	3.4	3.6
	9/21	36 (b)	80 (b)	(c)	(c)

Table 12 Con't. Tailings Characteristics Over Time By Chemical Stabilizer

Product	Date	Threshold Velocities		Moisture (%)	Silt (%)
		3 in. (a)	10 m		
Magnesium Chloride	5/28	44 (b)	80 (b)	(c)	(c)
	6/16	44	80	3.3	0.0
(Applied on wet tailings, tested on the dry areas)	7/8	16 (b)	25 (b)	(c)	(c)
	7/28	17	23	3.0 (b)	(b)6.5
	8/18	16	28	0.61	11.1
	9/21	16 (b)	25 (b)	(c)	(c)
Magnesium Chloride	5/28	43 (b)	80 (b)	(c)	(c)
	6/16	18 (b)	31 (b)	(c)	(c)
(Applied on dry tailings, tested on the dry areas)	7/8	18 (b)	31 (b)	(c)	(c)
	7/28	18	31	0.57	6.5
	8/18	17	35	0.33	5.8
	9/21	17	32	0.20 (b)	(b)10.0
Uncontrolled	7/31	23	40	0.46	8.3
	8/17	24	45	0.19	1.9
	8/17	19	37	0.12	0.26
	8/17	15	23	0.23	14.7
	9/22	26	40	1.1	0.80
	9/22	22	43	0.37	0.50
	9/22	24	40	0.40	1.0
	9/22	23	44	0.30	2.1

- (a) Height of measurement, 3 inches is the midpoint height of the wind tunnel, 10 meters is the 3 inch height velocity extrapolated to a height of 10 meters
- (b) Estimated value, usually based on an average of data before and after the value
- (c) Estimated value was not attempted

Figure 32. Test Run/Sample Locations

Fine Tailings

104 Coherex 12:1	Coherex 9:1	L.S. 8:1	L.S. 4:1	25 UC	Nalco 656	Nalco 655	Mg Cl2 (Dry)	Mg Cl2 (Wet)
36 32	31	30	29	45	27	41	42	
	37	38	39	25 26		28	19	
22 21				44				34
4		16	15	24	17	18		35
1 5		13	14					20
	6	7	8	43 42a			33	
	2			23	9	10	11	12

Coarse Tailings

The magnesium chloride, which utilizes moisture as the bonding agent showed a wide range of moisture contents. Moisture contents in excess of 3.0% were associated with high threshold velocities, and moisture contents less than 0.7% were associated with low threshold velocities. From this information, moisture content of the magnesium chloride treated surface can be used as a good indicator to determine the effectiveness of the applied chemical stabilizer.

For the other chemical stabilizers, silt content of the tailings surface can be used as an indicator to determine the effectiveness of an applied chemical stabilizer. Figure 33 presents the relationship of silt content to wind erosion threshold velocity (3 inch height) as per this study. As indicated in Figure 33, as the silt content of the tailings surface increases, there is a general lowering of the wind erosion threshold velocity. Appendix H presents this data normalized to a height of 10 meters.

#### 5.4 Chemical Stabilizer Product Usage Requirements

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The following sections discuss the usage requirements of the major dust control chemicals evaluated in the study. These requirements consist of product delivery methods, storage requirements, and specific application procedures.

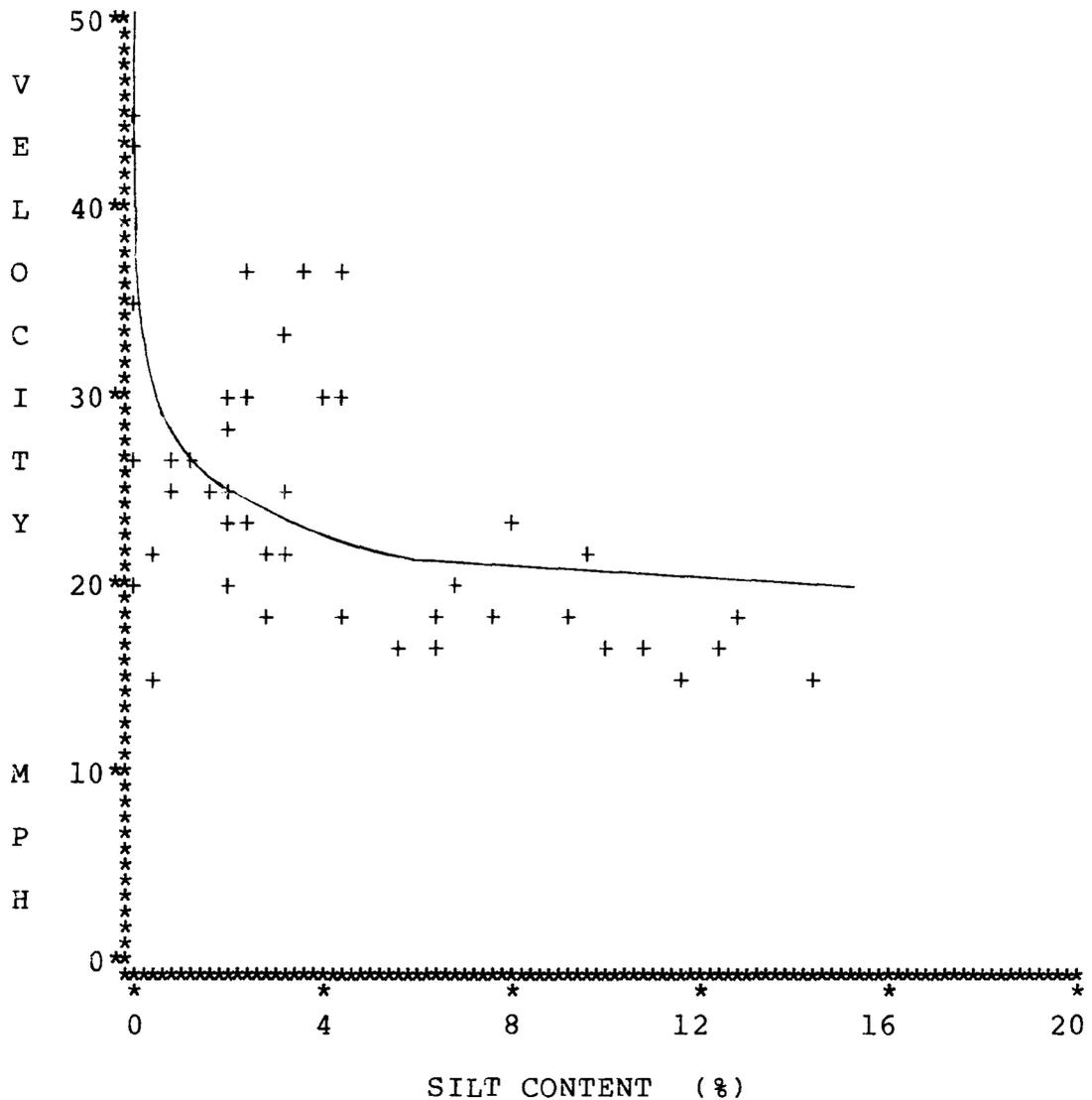
##### 5.4.1 Delivery Requirements

The selection of a chemical stabilizer may be contingent on the delivery requirements of the product vendor. Products such as Cohorex and lignosulfonate have been used in the mining industry for some time and the infrastructure for the delivery of the products are well established. Cohorex is available from a number of vendors throughout the United States. The product usually can be delivered in tanker truck/railcars or 55 gallon drums throughout the year. Winter shipments should be avoided because Cohorex will degrade if it should become frozen. Lignosulfonate is available from a number of sources nationwide as well. It does not have the extent of the freeze/thaw problems as Cohorex. It is available year round.

The Nalco chemicals and the magnesium chloride are relatively new products for tailings dust control and their delivery requirements may be more stringent than the two products previously mentioned. The Nalco products originate from the Chicago area, while the magnesium chloride originates from the Salt Lake City area. Transportation for the Nalco products is not necessarily tied to bulk truck or railcar shipments since relatively small amounts of chemical are used per acre. Fifty-five gallon drums of the product can be transported which reduces scheduling problems relative to railcar or tanker-truck

Figure 33.

TACONITE TAILINGS  
SILT CONTENT VS. WIND EROSION THRESHOLD VELOCITY  
(VELOCITY @ 3 INCH HEIGHT)



The best fit line equation is:

$$y = a x^b$$

Where  $a = 28.3$   
 $b = -0.044$   
 $x = \text{Silt Content}$

Note: The equation is valid only for silt contents between 0 - 15%

shipments. The magnesium chloride is usually sent by railcar and/or tanker-truck, due to the large quantities required for dust control purposes. If shipped during freezing conditions, and left unprotected, both of these products may be altered.

#### 5.4.2 Product Storage Requirements

Once the chemicals are delivered, either they are used directly from the vehicle which transported them (railcar or truck) or they are stored for further usage. Above ground storage tanks are required for long term storage. During cold weather periods, all the products, especially, Coherex, magnesium chloride, and the Nalco products should be kept from freezing. Freezing will degrade the chemicals. Many times plants will bury the storage tanks to protect against freezing. The lignosulfonate will not degrade to the extent of the other chemicals, however, the product may be nonusable due to an increase in viscosity.

The Nalco products can be purchased in drum containers. Since relatively small amounts of chemicals are required during application, a number of drums can be used as a storage system for this chemical versus bulk storage. The barrels should be protected from freezing temperatures.

#### 5.4.3 Product Application Requirements

All four of the chemical stabilizers evaluated in this study, are suitable for application from a pressure spray vehicle. Due to the stability of tailings, it is recommended a high floatation wheeled vehicle (rating in the range of 15 psi) with a 1,000 to 3,000 gallon holding tank be used. A standard roadway water wagon will not have the necessary floatation to be able to maneuver over the tailings.

Table 13 presents application considerations for the various chemical stabilizers. This information was gathered from both vendors and users of the products. As with all industrial chemicals, care should be taken to keep the materials from making skin or eye contact.

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Table 13 Chemical Stabilizer Application Considerations

Product	Consideration
-----	-----
CohereX	<ul style="list-style-type: none"> <li>* The water used to dilute the concentrate should have a pH no higher than 8.0. Values higher than this reduce the mixing properties of the chemical stabilizer.</li> <li>* The CohereX should be added to the vehicle holding tank after the majority of dilution water has been added. This reduces foaming within the holding tank.</li> <li>* The inside/outside of the holding tank and spray bar system should be rinsed with a suitable solvent after every use to reduce buildup of the chemical stabilizer.</li> <li>* The product is not water-soluble after drying. It requires a solvent to remove from hands and clothing.</li> <li>* If the product is applied onto tailings and undergoes freeze/thaw cycles, it is reported this will accelerate the degradation of the applied product.</li> </ul>
Calcium Lignosulfonate	<ul style="list-style-type: none"> <li>* The product is water-soluble. It probably should not be used during periods of the year of when rainfall amounts per day greater than 0.5 inches are experienced.</li> <li>* Although it is water-soluble, after drying it may clog the vehicle spray system. Rinsing the holding tank and spray system is recommended after use.</li> <li>* The product may be unworkable during below freezing temperatures, unless it is heated to above 40 degrees F.</li> <li>* Should the calcium lignosulfonate contaminate the milling plant process water, it could cause ore flotation problems. The ammonium lignosulfonate does not cause such a problem.</li> </ul>
Nalco 656 & 655	<ul style="list-style-type: none"> <li>* The product, when stored, should be well mixed prior to use. Both products separate readily during storage.</li> <li>* The product should be mixed gradually in with the water in the vehicle tank for proper mixing. If it is added in one dose, it will not disperse in the water properly and will clog the pressure spray system.</li> <li>* Even if the product is well mixed during the filling of the vehicle tank, the product may fall out of solution during the time it takes to travel from the staging area to the</li> </ul>

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 Table 13 Chemical Stabilizer Application Considerations -  
 Continued

Product	Consideration
Magnesium Chloride	<p>-----</p> <p>tailings basin. An internal pump should be used to keep the solution well mixed throughout the application process.</p> <ul style="list-style-type: none"> <li>* The vehicle holding tank and pressure spray system should be rinsing after use to avoid clogging from dried residue.</li> <li>* If the product is to be applied during the winter months, the make-up water should be heated to above 40 degrees F to facilitate mixing.</li> <li>* The tailings should be wet to a depth of at least one half inch prior to application. This aids the product in dispersing throughout the tailings surface. Application after a rainfall is desired.</li> <li>* The product is applied as delivered, without dilution. The high specific gravity of the applied magnesium chloride may reduce the pressure which the spray system of the application vehicle can deliver. This could alter the gallons applied at a set vehicle travel speed, relative to other chemicals.</li> <li>* If the product is used in the winter months, it should be checked for precipitate. This could clog the pressure spray system of the application vehicle.</li> </ul> <p>-----</p>

### 5.5 Costs of Chemical Stabilizers

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The total cost of a tailings dust control program includes product, labor, and equipment costs. The following sections discuss these costs.

#### 5.5.1 Product Costs

The cost of acquiring chemical stabilizers includes base product cost and shipping cost expressed on a dollar per gallon basis. Based on the dilution ratio and application dosage (gal./unit area) of the chemical stabilizer applied onto the tailings, a product applied cost, exclusive of labor cost, on a per acre basis can be determined. Table 14 presents the above information for the chemical stabilizers evaluated in this study.

-----  
 Table 14 Chemical Stabilizer Cost Data

Product/ Dilution	Purchase Cost (\$/gal.) (a)	Purchase & Shipping Cost (\$/gal.) (b)	Product Cost Per Acre (\$/acre) (c)
-----	-----	-----	-----
CohereX 12:1	1.20	1.50	140
9:1	1.20	1.50	182
Calcium			
Lignosulfonate 8:1	0.17	0.26	35
4:1	0.17	0.26	63
Nalco 656 (99.25:0.75)	8.80	8.93	81
655 (98:2)	8.16	8.29	200
Magnesium Chloride (not applied diluted)	0.24	0.86	2,080

- (a) Purchase cost of chemical stabilizer in concentrated form.  
 (b) Costs are based on bulk tanker-truck or railcar shipping costs to the Iron Range in northern Minnesota. The Nalco products are based on shipping 55 gallon drums.  
 (c) All products are applied at a dosage of 0.25 gallons per square yard. The exception is magnesium chloride, it is applied at 0.5 gallons per square yard. This applied cost does not include labor costs.
- 

As presented in Table 14, the least expensive of the applied dust control chemicals was the lignosulfonate. This cost reflects the fact that a source of the chemical (paper mills in northern Wisconsin) can deliver the chemical, with minimum shipping costs to the northern Minnesota site. If the chemical were to be delivered to the western United States, the product cost per acre would be more in the range of the CohereX and Nalco products (approximately \$195 per acre for the 4:1 and \$110 per acre for the 8:1 dilution). The magnesium chloride was the most expensive chemical on a product cost per acre basis. This is attributed to the costs of transporting the product from Utah to northern Minnesota. If the product was to be used in the western United States, the product cost per acre would be in the \$600-800 range.

#### 5.5.2 Labor And Equipment Costs

To assess the total costs of a dust control program, labor costs

and the cost of equipment (application vehicle etc.) should be added to the cost of the dust control chemicals. While labor and equipment usage costs vary from plant to plant, for estimation purposes, the labor and equipment costs incurred in this study will be used to as an example.

For the field study, a contractor experienced in the application of tailings dust control chemicals charged \$75 an hour for application services. This cost covered both labor and equipment. Assuming that chemicals can be applied onto 2.5 acres per hour, \$30 of costs, on a per acre applied basis, can be assigned to labor and equipment costs. These costs, when added to the product applied costs presented in Table 14, result in the total application costs for the chemical stabilizers. Table 15 presents the total application costs, on a per acre basis, for the chemical stabilizers evaluated in this study.

-----  
 Table 15 Field Application Costs

Product/Dilution	Field Application Cost (\$/acre)
CohereX 12:1	170
9:1	212
Calcium Lignosulfonate 8:1	65
4:1	93
Nalco 656	111
655	230
Magnesium Chloride	2,110

-----

As discussed in Section 5.5.1, the lignosulfonate would exhibit a total cost in the range of the CohereX and Nalco products if it was delivered to a location in the western United States (approximately \$225 per acre for the 4:1 and \$140 per acre for the 8:1). The magnesium chloride, if used in the western United States, would range in cost from \$630-830 per acre. The CohereX would change minimally in cost if another location in the United States was chosen for estimation purposes. This is due to the nationwide distribution system for the product. The Nalco products also would change minimally in costs, if this evaluation were based on another location, since transportation costs are small relative to the base product cost.

## 5.6 Control Cost Effectiveness Evaluation

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The cost effectiveness of a chemical stabilizer is defined as the dollars expended per acre to achieve an acceptable level of control. The cost effectiveness evaluation considers the total cost of a dust control program (product, labor, and equipment) as well as the frequency of chemical stabilizer application over the wind erosion season to achieve an acceptable level of control.

For the purpose of this study, control cost effectiveness for the evaluated chemicals is assessed at two theoretical acceptable control levels. One control level, for the reduction of wind erosion dust emissions, is 75% the other is 90+%. The period required for acceptable control is 90 days. This is the approximate length, in northern Minnesota, of each the spring and fall wind erosion periods.

Based on the chemical stabilizer control effectiveness values reported in Tables 5 and 6 (Section 5.1.1), which are based on one application dosage of the field evaluated chemical stabilizers, it is apparent that none of these dust control products would achieve a control efficiency of even 75% over a three month period. Subsequent applications for all the products evaluated would be required to achieve the desired 75% or 90+% level of control.

Table 16 presents the chemical stabilizer control cost effectiveness evaluation. The table includes: (a) the chemical stabilizers and applied dilution strengths, (b) the initial application dosage and related costs, (c) the intensity, frequency, and costs of subsequent application dosages, and (d) the overall cost effectiveness of the evaluated chemical stabilizers which achieve estimated dust control levels of 75% and 90+% over a three month period.

The required number of subsequent applications necessary to achieve the desired level of control were estimated by the results of the threshold velocity field testing, and conversations with plant users of dust control chemicals. At best, these chemical stabilizers require additional product application every 6 to 8 weeks during a wind erosion season (10).

For the more effective chemical stabilizers, (lignosulfonate 4:1, Nalco 656 & 655, and magnesium chloride) it is estimated only the initial and one subsequent application are required to achieve the desired control levels over the three month time period. The other chemicals, (Coherex 12:1 & 9:1 and lignosulfonate 8:1) required multiple subsequent applications in order to achieve the indicated control levels.

As explained in Section 5.5.1 and 5.5.2, due to the location of this study's evaluation, the northern Minnesota Iron Range, the

Table 16 Chemical Stabilizer Control Cost Effectiveness Evaluation  
For Northern Minnesota Iron Range

Product/Dilution	Initial Application Dosage (gal/yd)	Applied Cost (\$/acre)	Subsequent Application Dosage (gal/yd)	Subsequent Applications (75% (a) 90+%)	Required No. Subsequent Applications	Subsequent Application Costs (\$/acre) (75% (a) 90+%)	Subsequent Application Costs (\$/acre) (75% (a) 90+%)	Total Cost Per Wind Erosion Season (\$/acre) (a) 90+%
Coherex 12:1 9:1	0.25	170	0.25	2	3	340	510	680
	0.25	212	0.25	1	2	212	424	636
Lignosulfonate 8:1 4:1	0.25	65	0.25	1	2	65	130	195
	0.25	93	0.25	1	1	93	186	186
Nalco 656 655	0.25	111	0.25	1	1	111	222	222
	0.25	230	0.25	1	1	230	460	460
Magnesium Chloride-Wet Dry 0.5	0.5	2110	0.25	1	1	1055	3165	3165
	0.5	2110	0.25	1	1	1055	3165	3165
Control Cost Effectiveness Evaluation For Utah/Wyoming-Western United States								
Lignosulfonate 8:1 4:1	0.25	140	0.25	1	2	140	280	420
	0.25	225	0.25	1	1	225	450	450
Magnesium Chloride-Wet Dry 0.5	0.5	700	0.25	1	1	350	1050	1050
	0.5	700	0.25	1	1	350	1050	1050

(a) Level of desired dust control over a three month wind erosion season.

product delivered costs of the calcium lignosulfonate and the magnesium chloride affect considerably their associated cost effectiveness. Table 16 also presents the control cost effectiveness evaluation of these two products under the assumption that the location of the evaluation was in the Utah/Wyoming, western area of the United States. For this evaluation, the same parameters affecting control effectiveness, other than cost, remain the same relative to the northern Minnesota evaluation.

As presented at the bottom of Table 16, relative to the northern Minnesota evaluation, the control cost effectiveness would double for the lignosulfonate and would be reduced by two-thirds for the magnesium chloride. This change is due to the associated shipping costs for the two chemical stabilizers.

Table 17 summarizes the order of control cost effectiveness, presented in Table 16, ranging from the most to the least:

-----  
 Table 17 Control Cost Effectiveness For Northern Minnesota Iron Range

Desired Level Of Control			
75%		90+%	
(\$/acre/3 months)		(\$/acre/ 3 months)	
-----		-----	
1. Lignosulfonate 8:1	\$130	1. Lignosulfonate 4:1	\$186
2. Lignosulfonate 4:1	\$186	2. Lignosulfonate 8:1	\$195
3. Nalco 656	\$222	3. Nalco 656	\$222
4. Coherex 9:1	\$424	4. Nalco 655	\$460
5. Nalco 655	\$460	5. Coherex 9:1	\$636
6. Coherex 12:1	\$510	6. Coherex 12:1	\$680
7. Magnesium chloride	\$3165	7. Magnesium chloride	\$3165

Control Cost Effectiveness For Utah/Wyoming - Western U.S.A.

1. Nalco 656	\$222	1. Nalco 656	\$222
2. Lignosulfonate 8:1	\$280	2. Lignosulfonate 8:1	\$420
3. Coherex 9:1	\$424	3. Lignosulfonate 4:1	\$450
4. Lignosulfonate 4:1	\$450	4. Nalco 655	\$460
5. Nalco 655	\$460	5. Coherex 9:1	\$636
6. Coherex 12:1	\$510	6. Coherex 12:1	\$680
7. Magnesium chloride	\$1050	7. Magnesium chloride	\$1050

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## 6.0 CRITERIA FOR SELECTING CHEMICAL STABILIZERS

There are various requirements which a tailings dust control program should consider before selecting chemical stabilizers for application. These requirements include assessing: (a) the characteristics of the tailings surface, (b) the meteorological conditions expected during the lifetime of the applied products, (c) the control efficiency desired over time, (d) the probability of the chemical stabilizer affecting the milling plant recovery process, (e) special product usage requirements, and (f) overall product cost effectiveness.

### 6.1 Tailings Characteristics

-----

The two characteristics of the tailings which should be evaluated prior to selection of a chemical stabilizer include silt and moisture content. Coarse tailings or those having a silt content of less than 5%, probably do not require the application of chemical stabilizers. This is due to the high threshold velocities required to initiate the wind erosion process for these tailings and the relative lack of fines available for suspension. Conversely, tailings having a silt content greater than 5% are more susceptible to wind erosion and merit the addition of chemical stabilizers. Tailings with silt contents greater than 30% are very susceptible to wind erosion, and this process will start at low threshold velocities. Based on the results of the field testing in this study, insufficient information exists to enable recommendations for applying chemical stabilizers onto tailings having a wide range of silt contents.

The moisture content of the surface tailings also influences the susceptibility of the tailings to wind erosion. Tailings less than 0.75% moisture are considered dry and are susceptible to the erosion process. As the tailings increase in moisture, they become less likely to erode. At a moisture content of 3% they are considered wet.

If the moisture content of the surface tailings, could vary considerably over the lifetime of application, due to precipitation events or the raising of the pond water table, the control efficiencies of certain chemical stabilizers could be affected. The lignosulfonates are said to leach with rainfall amounts greater than 0.5 inches of rainfall. Although in this study appreciable rainfall amounts were encountered, the lignosulfonate did not appear to be significantly affected, relative to the other products.

One product which may be benefited by occasional increases in surface moisture is magnesium chloride. The more moisture the surface of the treated magnesium chloride tailings has available, the greater the expected control efficiency.

## 6.2 Meteorological Conditions

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The meteorological conditions expected during the lifetime of the applied chemical stabilizer governs its long term effectiveness. The effect of precipitation on chemical stabilizers has been discussed in the previous section. No one chemical, relative to the others, appeared to be significantly affected by the rainfall experienced during the field testing portion of this study.

Periods of high wind were experienced only immediately after the application of the chemical stabilizers. These high wind speeds coupled with 1.58 inches of rainfall tended to affect the Coherex 12:1, lignosulfonate 8:1 and magnesium chloride (applied onto dry tailings) more than the other chemicals. A reason for this is due to their associated application dosages. These three products, were applied at dilutions less than recommended. From this example, it is evident that decreasing the recommended dosage level of applied products will only hasten the lowering of control effectiveness, when stressed.

The effect relative humidity has on long term control efficiency could not be properly evaluated in this study. The magnesium chloride should respond favorably to high relative humidities (> 50%) since it has deliquescent properties. To what extent high or low relative humidity has on the other chemical stabilizers is not known.

The effect freeze/thaw cycles have on the coherency of the treated tailing surface was to be evaluated in this study, however, weather conditions prevented the proper testing of effects. The bonds binding particles treated with Coherex has been stated to be adversely affected by freeze/thaw cycles. No information could be gathered for such information concerning the other chemical stabilizers.

The effect surface temperature has on the long term control efficiency of the treated tailings is not known, but high temperatures (> 100 degrees F) may attribute to the reduction of control efficiency. The tailings treated with Coherex, lignosulfonate, and magnesium chloride all acquire dark coloration after application. The tailings treated with the Nalco product are lighter in color after application. The darker tailings do exhibit higher surface temperatures resulting from solar radiation, which could accelerate the aging process of the applied chemicals. Also, the dark coloration of the magnesium chloride treated tailings could accelerate the evaporation of moisture from tailings.

### 6.3 Recovery Problems

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If the intake water from the tailings pond is used for plant process water, it may be critical to assess at what concentrations of chemical stabilizer in the process water will adversely affect the ore flotation/recovery system. Although none of the evaluated chemical stabilizers exhibited such problems within the Taconite industry, other industries may be affected. Chemical stabilizers may be found in the plant process water in dilute concentrations due to leaching of the applied chemicals and through accidental spills.

### 6.4 Product Usage Requirements

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Before selecting a chemical stabilizer, an evaluation of the associated usage requirements of the chemical is needed. This will identify potential problems in: (a) scheduled delivery of the product, (b) onsite storage requirements, (c) handling problems, and (d) problems encountered during application. These various requirements have been previously mentioned in Section 5.5.

In summary, all the products evaluated in this study had virtually identical usage requirements. Exceptions or requirements deserving mention are: (a) the Nalco products can be delivered in 55 gallon drums, mitigating the need for a storage tank, when treating large acreage, (b) the chemicals stored should not be allowed to freeze, (c) care should be taken by the operator to keep chemicals off of the skin, and (d) care should be taken to insure the proper mixing of the Nalco products during all phases of the application process.

### 6.5 Control Effectiveness

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The expected control effectiveness from a chemical stabilizer is a major criteria when selecting a product. The results of the field evaluation in this study showed a wide range in the control effectiveness of the products two and four months after application. The measured control effectiveness values are reported in Section 5.1.

After a period of one month, only the magnesium chloride applied onto wet tailings, exhibited a control effectiveness greater than 90%. If monthly control effectiveness at this level is desired for a dust control program, subsequent application of the dust control chemicals will be required.

## 6.6 Cost Effectiveness

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After assessing the merits of the chemical stabilizers according to the previously mentioned selection criteria, the cost effectiveness of the chemicals most suitable for usage should be estimated. The procedure to determine cost effectiveness is presented in Section 5.6. The procedure consists of determining the total product, labor, and equipment costs necessary for the application and maintenance of the chemical stabilizers in order to achieve a desired level of dust control during a wind erosion season.

For the plant operator, the estimation of total costs can be performed using price quotes from product vendors, and approximating application labor and equipment costs. These estimated costs are easier to figure than the number of subsequent application dosages which are required to achieve the desired level of dust control. As a start, one may assume the values presented in Section 5.6.

A more precise estimation can be derived from establishing chemical stabilizer test plots and determining their associated control effectiveness. This can be performed, in order of increasing accuracy, by: (a) visually inspecting the test plots over time, (b) acquiring silt content data over time to measure control effectiveness, (c) utilize a field wind tunnel to measure the wind erosion threshold velocity over time to determine control effectiveness, and (d) utilize a field wind tunnel to measure dust emissions over time at various wind velocities to determine product control effectiveness.

## 7.0 CONCLUSIONS

The following conclusions have been derived from this investigation.

1. The control of tailings dust emissions by industry is being addressed to a greater extent than during the past.
2. Very few industrial plants have established dust control programs. Experimentation is occurring to determine the chemical stabilizer(s) best suited to the needs of the plant. Many experimental programs are inconclusive because the plants do not have the means to properly quantify the effectiveness over time of the chemical stabilizers.
3. While there are a number of chemical stabilizers available, only a few have widespread acceptance as being effective. These products include those from the categories of: petroleum resins, lignosulfonates, latexes, and salts.
4. In the past, specialized equipment necessary to apply the chemical stabilizers onto the tailings was not available. Currently, equipment does exist which is suitable for such purposes.
5. Criteria for selecting a chemical stabilizer and implementing a successful dust control program are related to:
  - (a) The characteristics of the tailing surface
  - (b) The meteorological conditions expected during the life time of the applied product
  - (c) The control efficiency desired over time
  - (d) Problems with the product affecting the milling plant recovery process
  - (e) Special product usage requirements, and
  - (f) Overall product cost effectiveness

6. The estimated control cost effectiveness of the field tested chemical stabilizers follows:

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Table 18 Control Cost Effectiveness Summary  
For Northern Minnesota Iron Range

Desired Level Of Control			
75%		90+%	
(\$/acre/3 months)		(\$/acre/ 3 months)	
-----		-----	
1. Lignosulfonate 8:1	\$130	1. Lignosulfonate 4:1	\$186
2. Lignosulfonate 4:1	\$186	2. Lignosulfonate 8:1	\$195
3. Nalco 656	\$222	3. Nalco 656	\$222
4. Coherex 9:1	\$424	4. Nalco 655	\$460
5. Nalco 655	\$460	5. Coherex 9:1	\$636
6. Coherex 12:1	\$510	6. Coherex 12:1	\$680
7. Magnesium chloride	\$3165	7. Magnesium chloride	\$3165

Control Cost Effectiveness For Utah/Wyoming - Western U.S.A.

1. Nalco 656	\$222	1. Nalco 656	\$222
2. Lignosulfonate 8:1	\$280	2. Lignosulfonate 8:1	\$420
3. Coherex 9:1	\$424	3. Lignosulfonate 4:1	\$450
4. Lignosulfonate 4:1	\$450	4. Nalco 655	\$460
5. Nalco 655	\$460	5. Coherex 9:1	\$636
6. Coherex 12:1	\$510	6. Coherex 12:1	\$680
7. Magnesium chloride	\$1050	7. Magnesium chloride	\$1050

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## 8.0 RECOMMENDATIONS FOR FURTHER RESEARCH

1. The control effectiveness over time of four widely used dust control products have been determined for the first time in this study. While the data reflects the tailings characteristics and meteorological conditions prevalent during the study period, the control effectiveness results may have been different under other sets of conditions. Other conditions may include: (a) variation in the silt content of the tailings, (b) lower amounts of precipitation, (c) higher wind speeds, (d) a wider range of temperatures, and (e) a lower daily relative humidity.

In order to determine the effectiveness of the chemical stabilizers under various sets of conditions, field testing of the chemical stabilizers should be performed at various locations within the United States. The results of this testing would show the effect differences in tailings silt content and meteorological conditions have on the longevity of the chemical stabilizers.

Such testing would be performed, utilizing the field wind tunnel technique, in the western United States under arid conditions and in the eastern and midwestern United States under moderate and humid/wet type conditions. This information would aid the operators of tailings basins in their selection of cost effective chemical stabilizers. Currently, the effectiveness data concerning the predominately used chemicals is lacking and the plant personnel do not have the means to determine this important parameter.

2. In conjunction with the above proposed study, or as a separate study, research could be performed to determine what chemical stabilizer application dosages are suitable for various silt content levels of tailings. The silt content of the tailings in this study ranged from 5% to 20%. Many plants have tailings silt contents in the 40% to 90% range. The general application dosage level reported by product vendors may not be suitable to treat all size fractions of fine tailings. Research to determine the most cost effective chemical stabilizer application dosage, for a range of tailings particle sizes, would be valuable information for plant personnel to utilize when selecting products.

3. As part of the above studies, or as a separate study, an increased data base of emission factors for controlled and uncontrolled tailings could be developed. A few emission factors were determined in this study and they exhibited a factor range of almost 1,500. Additional emission factor data would be useful to determine: (a) what extent dust emissions increase with incremental increases in wind speed, and (b) control efficiencies measured by emissions testing rather than threshold

velocity testing. These control efficiencies could be used to determine the amount of emissions actually reduced due to the use of a chemical stabilizer.

4. An old lead-zinc mining area exists in the southeastern portion of Kansas, in the vicinity of Galena. This area is characterized by a number of abandoned industrial process plants and a considerable acreage of lead-zinc tailings. The area has been designated as a hazardous waste site and is a site being considered for EPA Superfund clean-up. A high level of lung cancer is prevalent in the area, and researchers have attributed a portion of the lung cancer to the wind erosion dusts of the abandoned tailings.

Two reasearch programs are proposed to aid the control of these tailings windborne dusts. Research to determine the most cost-effective means of stabilizing the exposed tailings, during the high wind periods of the year, is proposed. Additionally, research could be conducted to determine whether chemical stabilization combined with vegetative stabilization would provide long lasting control of the hazardous, fugitive dust wind erosion emissions.

## 9.0 REFERENCES

1. Gillette, D. "Tests With A Portable Wind Tunnel For Determining Wind Erosion Threshold Velocities", Atmospheric Environment, Vol. 12, 1978.
2. Woods, D. and R. Chuan. "Aerosol Characterization With A Quartz Crystal Microbalance Cascade Impactor". Proceedings: Advances in Particle Sampling and Measurement. EPA-600/9-80-004, January 1980.
3. Chuan, R. "Rapid Measurement of Particulate Size Distribution in the Atmosphere". In: Fine Particles, Aerosol Generation, Measurement, Sampling, and Analysis. Benjamin Liu editor. Academic Press, New York, 1976.
4. Hodgin, R. "Logarithmic Wind Profile Parameters Applied To Air Quality Assessment Studies". Presented at Second Joint Conference (APCA-AMS) On Applications Of Air Pollution Meteorology. March 24-27, 1980.
5. U.S. Environmental Protection Agency. "Standards Of Performance For New Stationary Sources - Revisions To Reference Method 1-8". Federal Register, Vol. 42, August 18, 1977.
6. Annual Book of ASTM Standards. "C 136: Standard Method of Test For Sieve Or Screen Analysis Of Fine And Coarse Aggregates". American Society For Testing And Materials 1976.
7. Cowherd, C. et.al. "Development Of Emission Factors For Fugitive Dust Sources". EPA 450/3-74-037. June 1974.
8. Bohn, R. et.al. "Fugitive Emissions From Integrated Iron and Steel Plants. EPA 600/2-78-050. 1978.
9. Cowherd, C. and R. Bohn. "Iron and Steel Plant Open Source Fugitive Emission Evaluation". EPA 600/2-79-103. 1979.
10. Personnel Communication With Frank Scheuring. Erie Mining Company, Hoyt Lakes, Minnesota. November 12, 1981.

APPENDIX A. BIBLIOGRAPHY

## Tailings Pond-Design, Construction and Operation

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No. of sources: 5  
Years : 1977-1980

These papers investigate aspects of tailings ponds ranging from basic design parameters to properties of pumped tailings fill. Construction of tailings ponds, reclamation facilities and environmental considerations are also among the theme of these papers.

Soderburg, R.L. and R.A. Busch. "Design Guide for Metal and Non-metal Tailings Disposal", BM IC 8755 1977 136pp.

Sharma, D.K., Ratan, S., and Dhar, B.B. "Role of Soil Mechanics in Mining-With Special Reference to Mine Tailings Disposal", Journal of Mines, Metals and Fuels, Sept., 1977

Jones, J.D. and Jenkins, R.G. "Design and Construction of Tailings Ponds and Reclamation Facilities", CIM Bulletin, Vol. 71 No. 798, Oct. 1978

Oiling, G.W. "Environmental Considerations in Tailings Disposal", CIM Bulletin, Vol. 72 No. 801, Jan. 1979

Argall, George. "Tailings Disposal Today", Vol.2 Proc. of the Inter-tailings Symposium, 2nd. 1978.

Blight, G.E. "Properties of Pumped Tailings Fill", South African Inst. of Mining Metallurgy Jour., Vol.79 No. 15 Oct. 1979

U.S. Bureau of Mines, "Air and Water Pollution Controls", Engineering and Mining Jour. 181:156-8, June 1980

## Physical Mechanics of Stabilization

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No. of sources: 4  
Years : 1978-1979

Surfactants, adsorption principles and surface tension reducing agents are all discussed in these papers. Physical principles of stabilization and areas of needed investigation are reviewed as are the optimum conditions needed for stabilization.

Cheng, Lung (US Bureau of Mines). "Optimizing Water Sprays for Dust Suppression", Eng. Mining Journal Vol. 179 No. 10, Oct. 1978

"Dust Control", Mining Magazine, Vol. 140 No. 6, June 1979

Harrold, Robert. "Surfactants vs. Dust- Do They Work?", Coal Age, 84:102-5 June 1979

Casteline, John. "Fugitive Coal Dust Control", Power Engineering  
Vol. 83(7) July 1979

#### Plant Experience With Chemical Stabilization

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No. of sources: 7  
Years : 1974-1980

Surfactants, adsorption principles and surface tension reducing agents are all discussed in these papers. Physical principles of stabilization and areas of needed investigation are reviewed as are the optimum conditions needed for stabilization.

Brown, J.A. "Climax Fugitive Dust Control on Tailings Ponds",  
Proceedings Mineral Waste Stab. Liasons Comm., Hot Springs Ark.  
April 1974

Anons. "Chemical Agent Stabilizes Dust at Climax Tailings Ponds  
and Dams", Environ. Mining Jour., Vol. 175(6) June 1974

Eccles, A.G. "Pollution Control at Western Mines Myra Falls  
Operations." CIM Bull. v 70 n 785 Sept. 1977 p141-147

Anons. "Reserve Mining: An Epic Battle Draws to a Close",  
Environ. Sci. and Tech, Oct. 1979

Klohn, Earle J.; Dingeman, David. "Tailings Disposal System for  
Reserve Mining Company", Tailing Disposal Today, Vol 2: Proc. of  
the Int. Tailing Symp, 2nd, Denver, Colo. May 21-21 1978

Dickison, Samuel K. "Mineland Stabilization", 39th Annual Mining  
Symposium, Minnesota University, 1978

Anons. "Inco Finds Solution for Tailings Dust Control", Canadian  
Mining Jour. Vol. 101 (4) April 1980

Kuit, W.J. "Mine and Tailings Effluent Treatment at the  
Kimberly, B.C. Operations of Cominco Ltd. CIM Bulletin Vol. 73  
Dec. 1980

#### Chemical-Vegetative Stabilization

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No. of sources: 20  
Years : 1957-1982

These papers investigate the various chemicals and chemical and vegetative techniques that have been used as stabilization agents and their subsequent success rates. Lignin sulfonates, plastic resins, magnesium chloride, latex and elastomeric polymers are an example of the agents involved. Application

rates, application machinery, optimum conditions for application and economic considerations are reviewed .

Harmon, John P. "Use of Lignin Sulfonate for Dust Control on Haulage Roads in Arid Regions." BOM information Circular, 1957

"Roadbinder: Why Chino Division Treats Mine Roads." Mining World Vol. 20 No. 9, August 1958

Dobbs, J.B., and Marie Hitchcock. "Development of a Soil Treatment Material to Serve as a Dust Palliative in the Theater of Operations.", U.S. Army, Oct. 1967

Murdock, Captain L.W. "Military Potential Test of Dust Control Materials.", U.S. Army, Feb. 1969

Dean, Karl C., Richard Havens, and Kimbal T. Harper. "Chemical and Vegetative Stabilization of Nevada Copper Porphyry Mill Tailing." Report of Investigations 7261, BOM, 1969

Dean, Karl C., R. Havens, and E.G. Valdez. "Stabilization of Mineral Wastes", Industrial Water Engineering, Oct. 1969

Dean, Karl C., R. Havens. "Chemical Stabilization of the Uranium Tailings at Tuba City, Ariz., BOM RI 7288, 1969

Lyles, Leon; Armbrust, D.V.; Dickerson, J.D., and N.P. Woodruff. "Spray on Adhesives for Temporary Wind Erosion Control", Jour. of Soil and Water Conservation, Sept.- Oct. 1969

Dean, Karl C., R. Havens. and E.G. Valdez. "Progress in Using and Stabilizing Mineral Wastes", AIME Fall Meeting St. Louis, Mo. Oct. 1970

Dean, Karl C., and Richard Havens. "Stabilizing Mill Tailings", Presented at the Nat. Western Mining Conferance, Denver, Colo. 1970

Dean, Karl C., R. Havens. "Stabilizing Mineral Waste", Eng. and Mining Jour., Vol. 172 April 1971

Armbrust, D.V., and J.D. Dickerson. "Temporary Wind Erosion Control : Cost and Effectivness of 34 Commercial Materials." Jour. of Soil and Water Conservation, Vol. 26 No. 4, 1971

Dean, Karl C, Havens, R., and E.G. Valdez. "USBM Finds Many Routes to Stabilizing Mineral Waste", Mining Engineering, Dec. 1971

Dean, Karl C., Havens, R. "Comparative Costs and Methods for Stabilization of Tailings" Proc. of World Mining Int. Tailing Symp., Tucson, Arizona Oct., 1972

Dean, Karl C. and R. Havens. "Reclamation of Mineral Mining Wastes" AIME Meeting, San Fran., Calif. Feb. 1972

Dean, Karl C. and R. Havens. "Methods and Costs for Stabilizing Tailings Ponds" American Mining Congress Convention, Denver, Colo. 1973

Shirts, M.B., W.R. McDonald, M.W. Glantz, and G.M. Potter "Progress in Stabilizing Mineral Waste" Proc. of the Forth Mineral Waste Utilization Symp., May, 1974

Dean, Karl C., Havens, R., and M.W. Glantz. "Methods and Costs for Stabilizing Fine Sized Mineral Wastes", BOM RI 7896, Aug. 1974

Dean, Karl C., Potter, G. "Use of Polymers for Stabilizing Mineral Waste", Recycling and Disposal of Solid Wastes, Industrial Agricultural, Domestic. Ann Arbor Science Pub., Inc., 1974

Shirts, M.B. and J.H. Bilbrey Jr. "Stabilization Methods for the Reclamation of Tailings Ponds." Presented at the seminar "Landscaping and Land Use Planning as Related to Mining Operations", Adelaide, Australia. 1976

Nelson, C.R.; Yardley, P.H., and Lacabonne, W.D. "Mitigation of Dust from Taconite Tailings", Minn. Univ. 38th Annual Mining Symp. 1977

McDonald, W.R., Shirts, M.B. "Progress in Stabilizing Acidic Copper Tailings at Holden Village, Wash.", BOM RI 8314, 1978

Anon., "Dust Control", Mining Magazine, Vol. 140 No. 6 June, 1979

Harrold, R. "Surfactants vs. Dust; Do they Work?", Coal Age, Vol. 84 June 1979

Yardely, D.H.; Lacabonne, W.D., and C.R. Nelson "Airborne Dust from Taconite Tailings", US Bureau of Mines Nov. 1980

Bohn, Russell; Cuscino, Thomas; Lane, Dennis. "Dust Control for Haul Roads" US Bureau of Mines JO285015 Feb. 1981

Larson, Alan G., Schearer, Donald L., "Preliminary Report- Chemical Road Dust Suppressants", TRC Consultants, Englewood, Co. June 1982

Singer, Rexford D., Stevens, J. B., Gleason, J.R., Baker, D.A., and McEmber, A.V. "An Environmental Evaluation of Dust Suppressants: Calcium Chloride and Lignin Sulfonates", BOM contract no. H0212027 June 1982

Russell, D; and Caruso, Charles S. "A Survey of Chemical Dust Suppressants Utilized within the Iron and Steel Industry and Some other Industries", Mellon Institute of Research, Jan. 1982

## CohereX

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No. of sources: 8  
Years: 1964-1978

CohereX and its characteristics are reviewed in these papers. Results are reported from both plant application and laboratory research regarding this petroleum based resin. Suggested application rates, dilution rates and handling procedures are presented.

Peters, John, and Joe Sciandrone. "Stabilization of Sand Dunes at Vandenberg Air Force Base", Jour. of the Soil Mechanics and Foundations Div; Proc. of the American Society of Civil Engineers, 90 (SM-4), July 1964

Rostler, F.S., and W.M. Kunkel Jr. "Soil Stabilization" Industrial and Engineering Chemistry, Vol. 56(4), April 1964

Public Works. "Barren Areas Treated for Dust Control", Vol.97 (10), October 1966

Anos. "Chemical Treatment of Waste Tailings Puts An End To Dust Storms", Engineering and Mining Journal, April 1971

Canessa, William, "Dust Retardants", Air Pollution Control and Design Handbook, Marcel Dekker Inc.; 1977

Ross, Jerry L. "Chemical Eliminates Haul Road Dust" Coal Age, June 1977

Mine Mouth Haul Problem", Electrical World, Vol 189 No. 65, March 1978

Anons. "Dust Retardant Keeps Mountain Air Clean", Highway and Heavy Construction, Vol. 122 June 1979

## Foam Suppressants

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No. of sources: 2  
Years : 1978-1979

The application of foam as a suppressant and its advantages and disadvantages are reported. The history of foam suppression is reviewed with information on low expansion or "protein" foam, high expansion foam and pressure foam.

Cole, Howard W. "Foam Suppressants for Control of Dust", Coal Mining and Processing, Vol 14 No. 10, 1977

"Microfoam for Dust Control", CIM Bulletin Vol. 72 No. 215 March 1977

## Wind and Soil Erosion

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No. of sources: 21

Years : 1911-1978

Soil drifting, characteristics of soil movement and soil erosion principles are reviewed in these papers. The physics of wind erosion, aerodynamics of wind erosion, threshold velocities and reduction of wind erodibility are investigated. This wide range of papers covers most physical principles of soil and wind erosion and reviews factors that influence erodability.

Moss, H.C. "Some Field and Laboratory Studies of Soil Drifting in Saskatchewan", Scientific Agricultural Vol. 15 No. 10 June 1935

Chepil, W.S. and Milne, R.A. "Comparative Study of Soil Drifting in the Field and in a Wind Tunnel", Scientific Agricultural Vol. 19, 1939

Chepil, W.S. "Dynamics of Wind Erosion: I-VI", Soil Sci. Vol. 60 and 61 1945-46

Chepil, W.S. "Properties of Soil Which Influence Wind Erosion: I The Governing Principle of Surface Roughness", Soil Sci. Vol. 69, 1950

Zingg, A.W. and W.S. Chepil " Aerodynamics of Wind Erosion" Agri. Engineering, Vol. 31 No. 6, 1950

Chepil, W. S. "Properties of Soil Which Influence Wind Erosion: III Effect of Apparent Density on Erodibility" Soil Sci., Vol. 71, 1951

Chepil, W.S. "Factors That Influence Clod Structure and Erodibility of Soil By Wind: I. Soil Structure", Soil Sci., Vol. 75, 1952.

Chepil, W.S. "Improved Rotary Sieve for Measuring State and Stability of Dry Soil Structure", Soil Sci., Vol. 16 No. 2, April 1952.

Chepil, W.S. "Factors That Influence Clod Structure and Erodibility of Soil by Wind: III Calcium Carbonate and Decomposed Organic Matter.", Soil Sci. Vol. 77, 1954

Woodruff, N.P., and W.S. Chepil. "Implements for Wind Erosion Control", Agri. Engineering, Nov. 1956

Chepil, W.S. "Conversion of Relative Field Erodibility to Annual Soil Loss by Wind", Soil Sci. Vol. 24 No. 2, 1960

Chepil, W.S., and N.P. Woodruff "The Physics of Wind Erosion and

Its Control", Advan. in Agron. Vol. 15, 1963

Woodruff, N.P., and F.H. Siddoway. "A Wind Erosion Equation". Soil Sci. Vol. 29 No. 5, 1965

Lyles, L., and J.D. Dickerson. "General Design Criteria for Impact Tools to Increase Cloddiness Potential and Reduce Wind Erodibility of Sandy Loam Soils", Trans. Of the ASAE, 1967

Smalley, Ian J. "Cohesion of Soil Particles and the Intrinsic Resistance of Simple Soil Systems to Wind Erosion", Jour. of Soil Sci. Vol. 21 No.1, 1970

Lyles, L., R.L. Schrandt, and N.F. Schmeidler. "How Aerodynamic Roughness Elements Control Sand Movement", Trans. of the ASAE Vol. 17 No. 1, 1974.

Lyles, L., and B.E. Allison. "Wind Erosion: The Protective Role of Simulated Standing Stubble", Trans. of the ASAE 1976

Fryrear, D.W., and Leon Lyles. "Wind Erosion Research Accomplishments and Needs", Trans. of the ASAE, 1977

Lyles, Leon. "Wind Erosion: Processes and Effect on Soil Productivity", Trans. of the ASAE, 1977

Morrison, W.R., and L.R. Simmons. "Chemical and Vegetative Stabilization of Soils", (Erosion Control) Bureau of Reclamation, Dept. of the Interior, REC-ERC-76-13, Jan. 1977.

Dideriksen, R.I., "Erosion Inventory-Sheet and Rill Erosion", Amer. Soc. of Agric. Engineers, Paper No. 78-2514, 1978 winter meeting, Chicago, Ill.

#### Wind Tunnel Experimentation- Application

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No. of sources: 9  
Years : 1951-1978

These papers review various applications of wind tunnel usage and development. Aerodynamics of wind erosion, turbulence intensities, dust dispersion and velocity thresholds are all investigated with the use of wind tunnels. Problems encountered in field usage plus suggestions on design construction and data evaluation are presented.

Zingg, A.W. and N.P. Woodruff. "Calibration of a Portable Wind Tunnel for the Simple Determination of Roughness and Drag on Field Surfaces" Agronomy Journal, Kansas Agr. Station, Manhattan, Kansas July 13, 1951

Zingg, A.W. "A Portable Wind Tunnel and Dust Collector Developed

to Evaluate the Erodibility of Field Surfaces", Agron. J. Vol. 43 No. 4, 1951

Wooding, R.A. "A Low Speed Wind Tunnel for Model Studies in Micrometeorology", Commonwealth Scientific and Industrial Research Organization, Australia Melbourne, 1968

Lyles, L., and R.K. Krauss. "Threshold Velocities and Initial Particle Motion as Influenced by Air Turbulence", Trans. of the ASAE, 1971.

Lyles, L., L.A. Disrud, and R.K. Krauss. "Turbulence Intensity as Influenced by Surface Roughness and Mean Velocity in a Wind-Tunnel Boundary Layer", Trans. of the ASAE, 1971.

Gillette, Dale E., and I.H. Blifford, Jr. "Measurements of Aerosol Size Distributions and Vertical Fluxes of Aerosols on Land Subject to Wind Erosion", Jour. Apl. Meteorol. Vol. 11, 1972.

Mikhailov, V.A.; and V.G. Borisov. "Wind Loading of Films of Bituminous Emulsion", Soviet Mining Science, Vol. 11(1), Jan.-Feb. 1975

Gillette, Dale. "Tests With a Portable Wind Tunnel for Determining Wind Erosion Threshold Velocities", Atmospheric Environment, Vol. 12, 1978

Gillette, Dale, John Adams, Daniel Muhs, and Rolf Kihl. "Threshold Friction Velocities and Rupture Moduli For Crusted Desert Soil For The Input Of Soil Particles Into The Air", 1981. (Obtained From Author, To Be Published)

Furarola, G., Testino, S. and Ferraiolo, G. "Wind Erosion Of Storage Piles And Dust Dispersion In Scale Model Wind Tunnel Experiments", University di Genova. 1978.

#### Fugitive Emissions-Control

No. of sources: 5  
Years: 1976-1979

These papers investigate particulate control for fugitive dusts resulting from the mining industry. Air quality analysis, emission calculations and methods of control are discussed.

Reed, A.K.; Meeks, H.C. and S.E. Pomeroy. "Assessment of Environmental Aspects of Uranium Mining and Milling", Battelle Laboratories 68-02-1323 Dec. 1976

Boegman, N. "Air Pollution and the Metalurgical Industry", J.S. African Inst. Min. Metal. v 78 n1 Aug. 1977

Bohn, Russell; Cuscino, Thomas and Chatten Coward, Jr. "Fugitive Emissions from Integrated Iron and Steel Plants", EPA- 600/2-78-050 March 1978

Weant, George E. and B.H. Carpentry. "Particulate Control for Fugitive Dusts" EPA-600/7-78-071. EPA, IERC, RTP, April 1978.

Maxwell, C.M and C.Reed Hodgkin. "Iron Range Air Quality Analysis. Minn. Pollution Control Agency. June 5, 1979.

APPENDIX B. DUST CONTROL CHEMICAL STABILIZERS

Table B1 DUST CONTROL PRODUCTS

Category	Company Name	Product Name
Fabric	-	Burlap, Cheesecloth Plastic covers
Latex	Nalco Chemical Co. Bordon Chemical Co. Firestone Co. Dow Chemical Co. Alcoa Chemical Co. Johnson & March Co. Wen Don Chemical Co.	655(8803) & 656 Polyco 2440 FR-S 275 M 166,167 Soil Guard SP 301, 400 CPB-12
Lignosulfonate	Flambeau Paper Co. Arthur Trask Co. Crown Zellerbach Co. American Can Co. Ohm Research Products Co. Protex Industries Co. Southland Co. Woodchem Co.	Flambinder, N, NX Trastan CM-50, 57 Orzan AL & GL 50 Norlig 50 & 58 Dust-Bond 100 Soiltex Peritan & Trastan Woodchem ALS, HP, AB
Petroleum Resins	Witco Chemical Co. Hercules Co. Arco Mine Sciences Co. Armak Chemical Co. Syntech Inc.	Coherex XDS-1 Wind Loss Binder Neoprine Emulsion Dustex, Petro-Tac
Plastics	Bordon Chemical Co. Rohm & Hass Co. Celtite, Inc. Heuley and Company, Inc. E.F. Houghton The Fire Water Co. American Hoechst	Polyco 2607 Acrylic DLRMS Polybind DLR 801 Rezusol Crust 500 Curasol
Salts	Great Salt Lakes Minerals & Chemicals Co. Dow Chemical Co. Universal Energy Service Wen Don Chemical Co.	Magnesium Chloride Calcium Chloride Calcium/Sodium Chloride Magnesium Chloride

APPENDIX C. FIELD APPLICATION EQUIPMENT

Table C1 FIELD APPLICATION EQUIPMENT

Company	Model	Capacity (Gallons)	Cost (\$)
Ag-Chem Equipment Co. Inc.	1004	1,000	70,000
	2004	1,600	80,000
	1603	1,600	82,000
	2505	2,800	150,000
Big Wheels, Inc.	8002	1,600	85,000
Field Gymmy, Inc.	2000	2,000	50,000 - 75,000
Hayden Co. Inc.	HiWheeler	2,000	45,000 - 60,000
Rickel Manufacturing Corp.	2600	1,555	75,000
	3500	1,555	96,000
	4500	2,400	120,000

APPENDIX D. COMPANIES SURVEYED

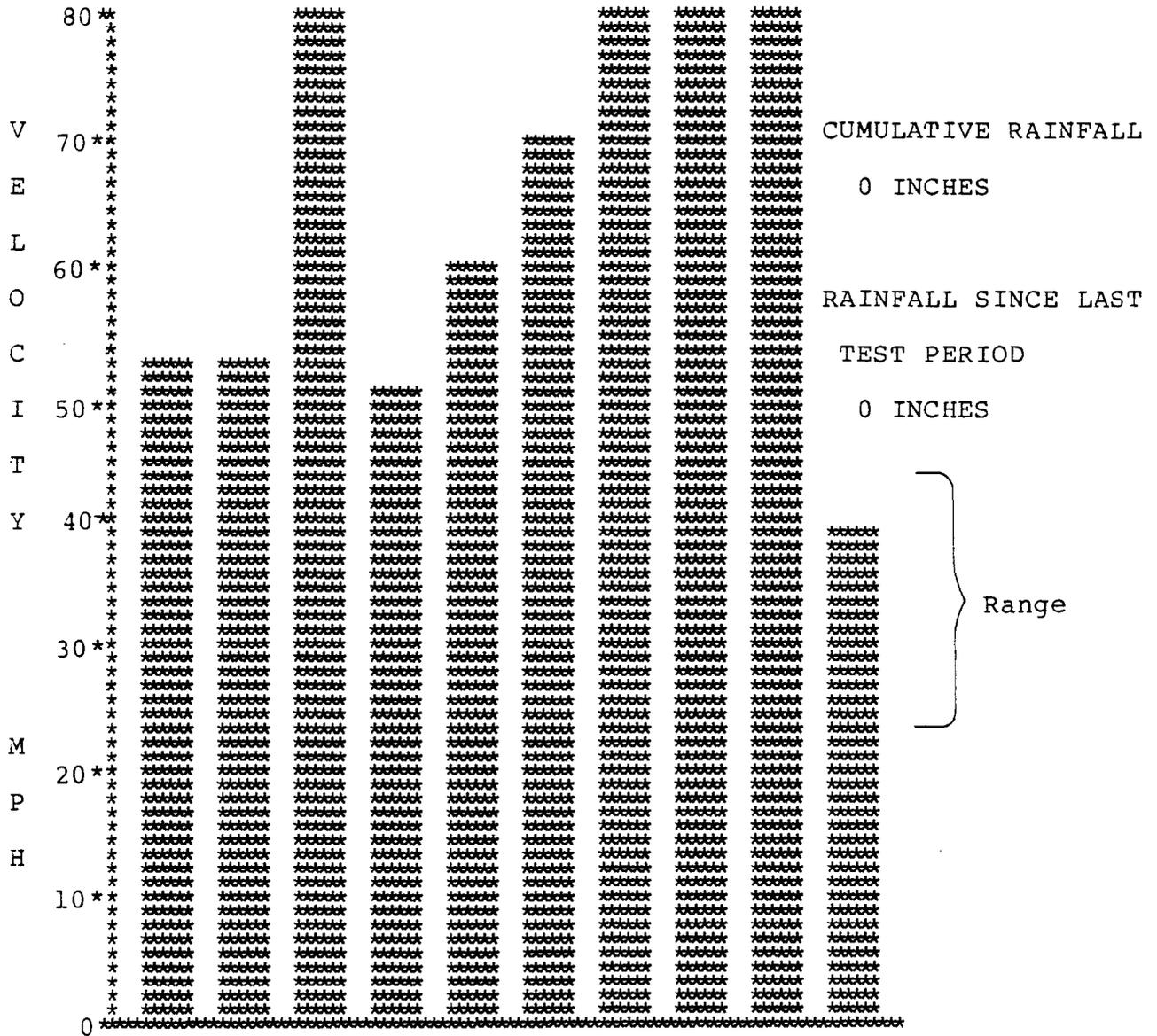
Table D1 SITE - TELEPHONE SURVEYS

Company	Location	Industry	Chemical Stabilizers
Reserve Mining Co.	Silver Bay, MN	Taconite	Coherex
Erie Mining Co.	Hoyt Lakes, MN	Taconite	Calcium and ammonium lignin sulfonate, Coherex
Eveleth Mining Co.	Eveleth, MN	Taconite	Coherex, Dowell M166
National Steel Co.	Keewatin, MN	Taconite	Coherex, Nalco 656
U.S. Steel Corp.	Mount Iron, MN	Taconite	Nalco 656, Coherex, Calcium lignin sulfonate
Kennecott Minerals Co.	Salt Lake City, UT	Copper	Coherex, Dowell J-196 Magnesium chloride
Atlas Minerals Co.	Moab, UT	Uranium/Vanadium	Coherex, Nalco 656
Federal American Partners	Riverton, WY	Uranium	Nalco 326, 8820, 8808, Coherex, Magnesium chloride, Calcium lignin sulfonate
Climax Molydenum	Climax, CO	Molybdenum	ARCO Wind Loss Binder 20-10, 2000, Nalco 655, 8820, Sodium lignin sulfonate, Coherex, Magnesium chloride Calcium chloride
Henderson Mill	Parshall, CO	Molybdenum	Coherex

APPENDIX E. WIND EROSION THRESHOLD VELOCITY PER MEASUREMENT  
PERIOD: 10 METER HEIGHT

Figure E1.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 1 (5/28)  
 (VELOCITY @ 10 METER HEIGHT)

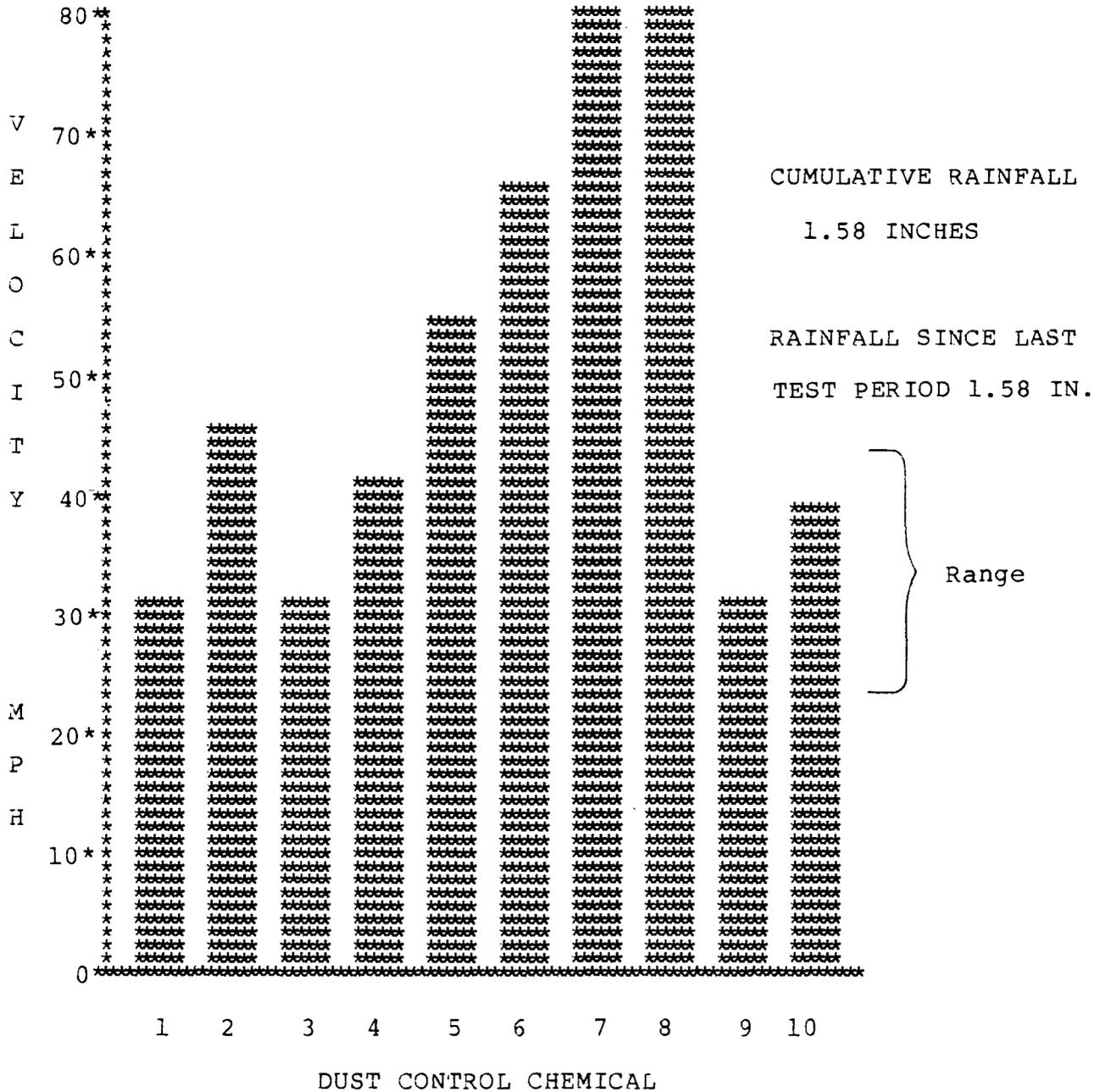


DUST CONTROL CHEMICAL

- |   |                    |    |                    |             |
|---|--------------------|----|--------------------|-------------|
| 1 | CohereX 12:1       | 6  | Nalco 655          | (Tested On) |
| 2 | CohereX 9:1        | 7  | Magnesium Chloride | Wet, Wet    |
| 3 | Lignosulfonate 8:1 | 8  | Magnesium Chloride | Dry, Dry    |
| 4 | Lignosulfonate 4:1 | 9  | Magnesium Chloride | Dry, Dry    |
| 5 | Nalco 656          | 10 | Uncontrolled Mean  |             |

Figure E2.

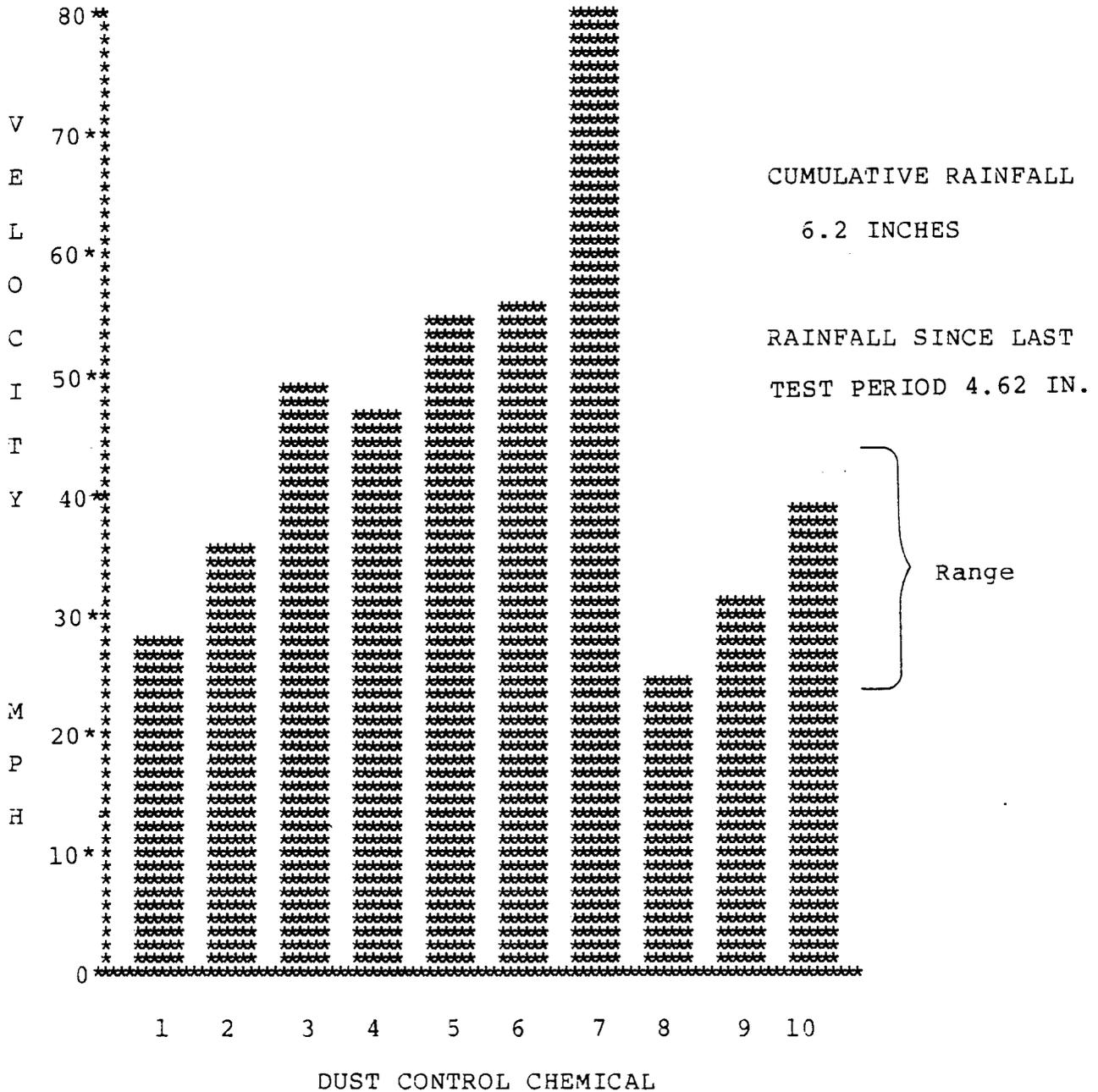
WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 2 (6/15)  
 (VELOCITY @ 10 METER HEIGHT)



- |   |                    |    |                    |             |
|---|--------------------|----|--------------------|-------------|
| 1 | Coherex 12:1       | 6  | Nalco 655          | (Tested On) |
| 2 | Coherex 9:1        | 7  | Magnesium Chloride | Wet, Wet    |
| 3 | Lignosulfonate 8:1 | 8  | Magnesium Chloride | Dry, Dry    |
| 4 | Lignosulfonate 4:1 | 9  | Magnesium Chloride | Dry, Dry    |
| 5 | Nalco 656          | 10 | Uncontrolled       | Mean        |

Figure E3.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 3 (7/8)  
 (VELOCITY @ 10 METER HEIGHT)

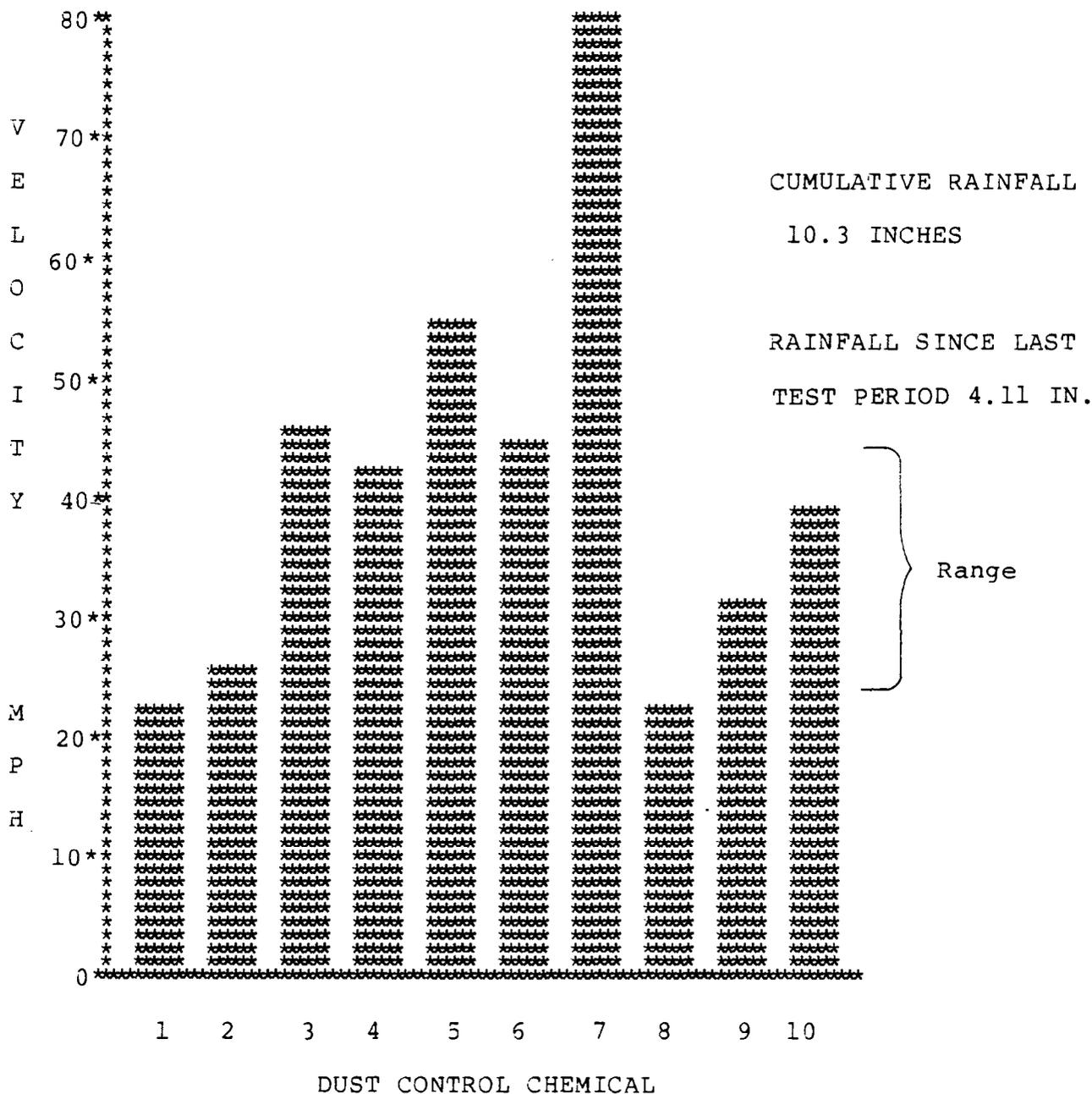


- |                      |                               |             |
|----------------------|-------------------------------|-------------|
| 1 Coherex 12:1       | 6 Nalco 655                   | (Tested On) |
| 2 Coherex 9:1        | 7 Magnesium Chloride Wet, Wet |             |
| 3 Lignosulfonate 8:1 | 8 Magnesium Chloride Dry, Dry |             |
| 4 Lignosulfonate 4:1 | 9 Magnesium Chloride Dry, Dry |             |
| 5 Nalco 656          | 10 Uncontrolled Mean          |             |

Figure E4.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 4 (7/31)

(VELOCITY @ 10 METER HEIGHT)

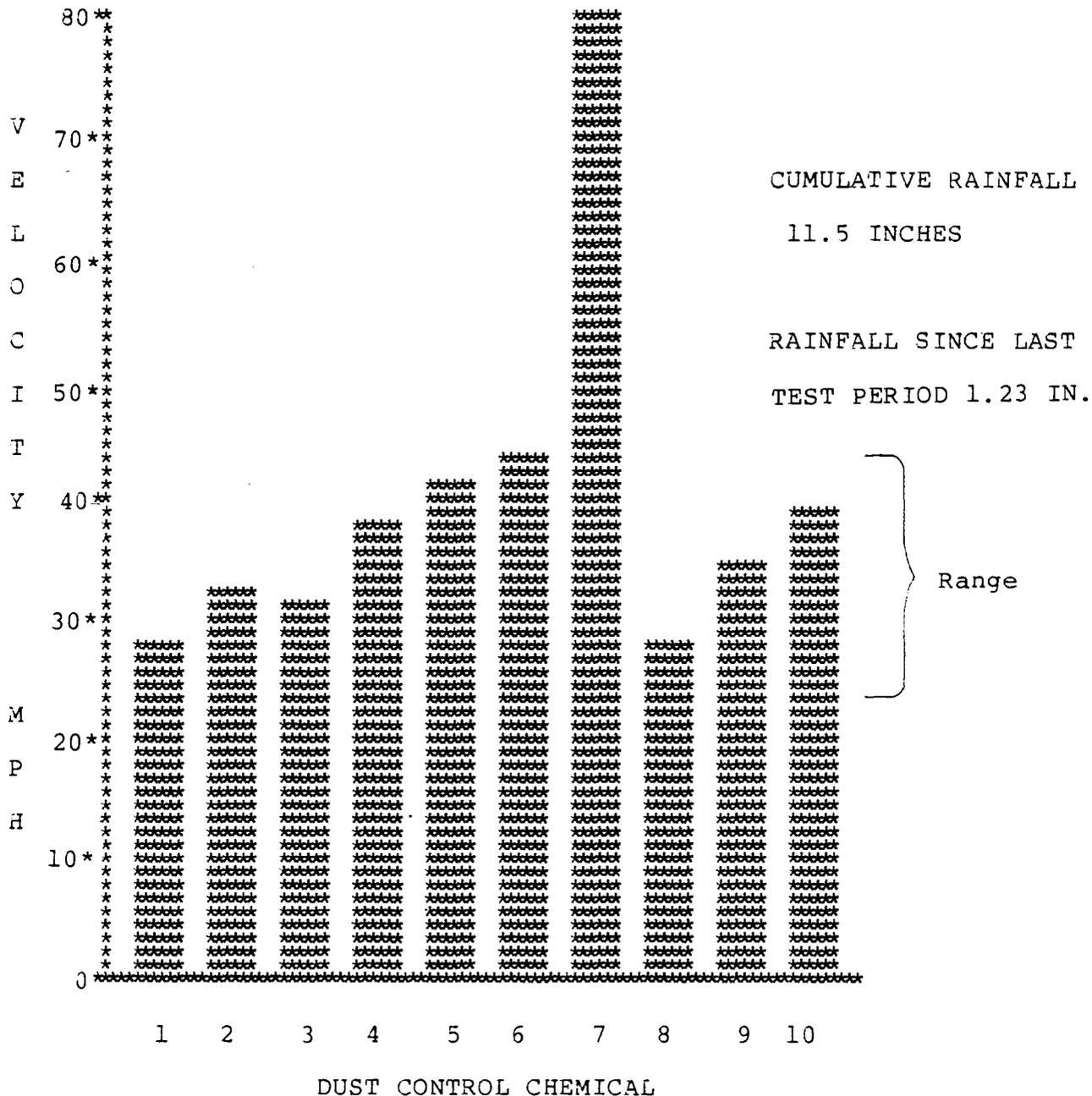


- |   |                    |    |                             |             |
|---|--------------------|----|-----------------------------|-------------|
| 1 | Coherex 12:1       | 6  | Nalco 655                   | (Tested On) |
| 2 | Coherex 9:1        | 7  | Magnesium Chloride Wet, Wet |             |
| 3 | Lignosulfonate 8:1 | 8  | Magnesium Chloride Dry, Dry |             |
| 4 | Lignosulfonate 4:1 | 9  | Magnesium Chloride Dry, Dry |             |
| 5 | Nalco 656          | 10 | Uncontrolled Mean           |             |

Figure E5.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 5 (8/17)

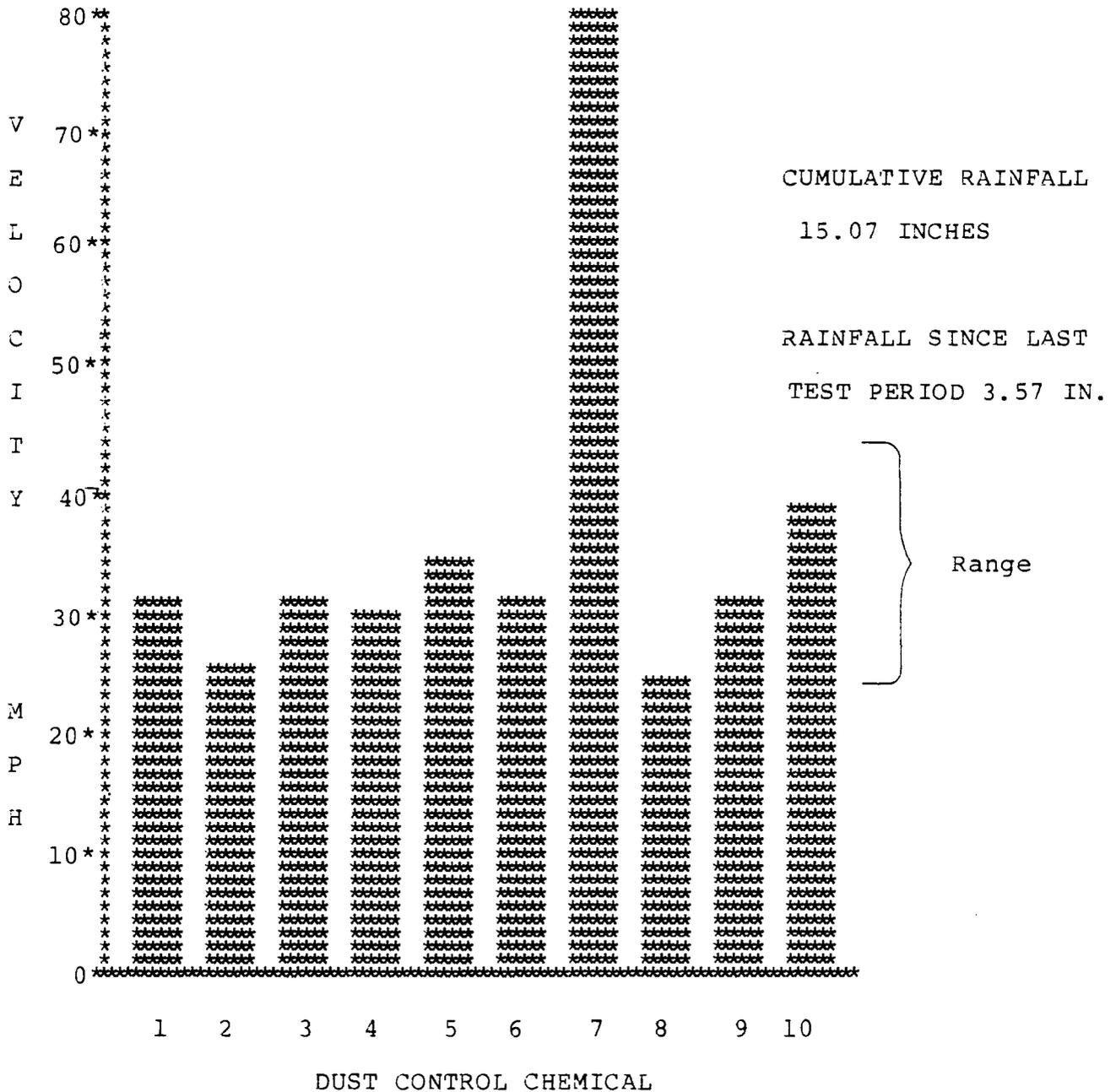
(VELOCITY @ 10 METER HEIGHT)



- |   |                    |    |                    |             |
|---|--------------------|----|--------------------|-------------|
| 1 | Coherex 12:1       | 6  | Nalco 655          | (Tested On) |
| 2 | Coherex 9:1        | 7  | Magnesium Chloride | Wet, Wet    |
| 3 | Lignosulfonate 8:1 | 8  | Magnesium Chloride | Dry, Dry    |
| 4 | Lignosulfonate 4:1 | 9  | Magnesium Chloride | Dry, Dry    |
| 5 | Nalco 656          | 10 | Uncontrolled       | Mean        |

Figure E6.

WIND EROSION THRESHOLD VELOCITIES DURING PERIOD 6 (9/21)  
 (VELOCITY @ 10 METER HEIGHT)



- |                      |                               |             |
|----------------------|-------------------------------|-------------|
| 1 Cohorex 12:1       | 6 Nalco 655                   | (Tested On) |
| 2 Cohorex 9:1        | 7 Magnesium Chloride Wet, Wet |             |
| 3 Lignosulfonate 8:1 | 8 Magnesium Chloride Dry, Dry |             |
| 4 Lignosulfonate 4:1 | 9 Magnesium Chloride Dry, Dry |             |
| 5 Nalco 656          | 10 Uncontrolled Mean          |             |

APPENDIX F. WIND EROSION THRESHOLD VELOCITY OVER TIME: 10 METER  
HEIGHT

Figure Fl.

WIND EROSION THRESHOLD VELOCITY OVER TIME  
(VELOCITY @ 10 METER HEIGHT)

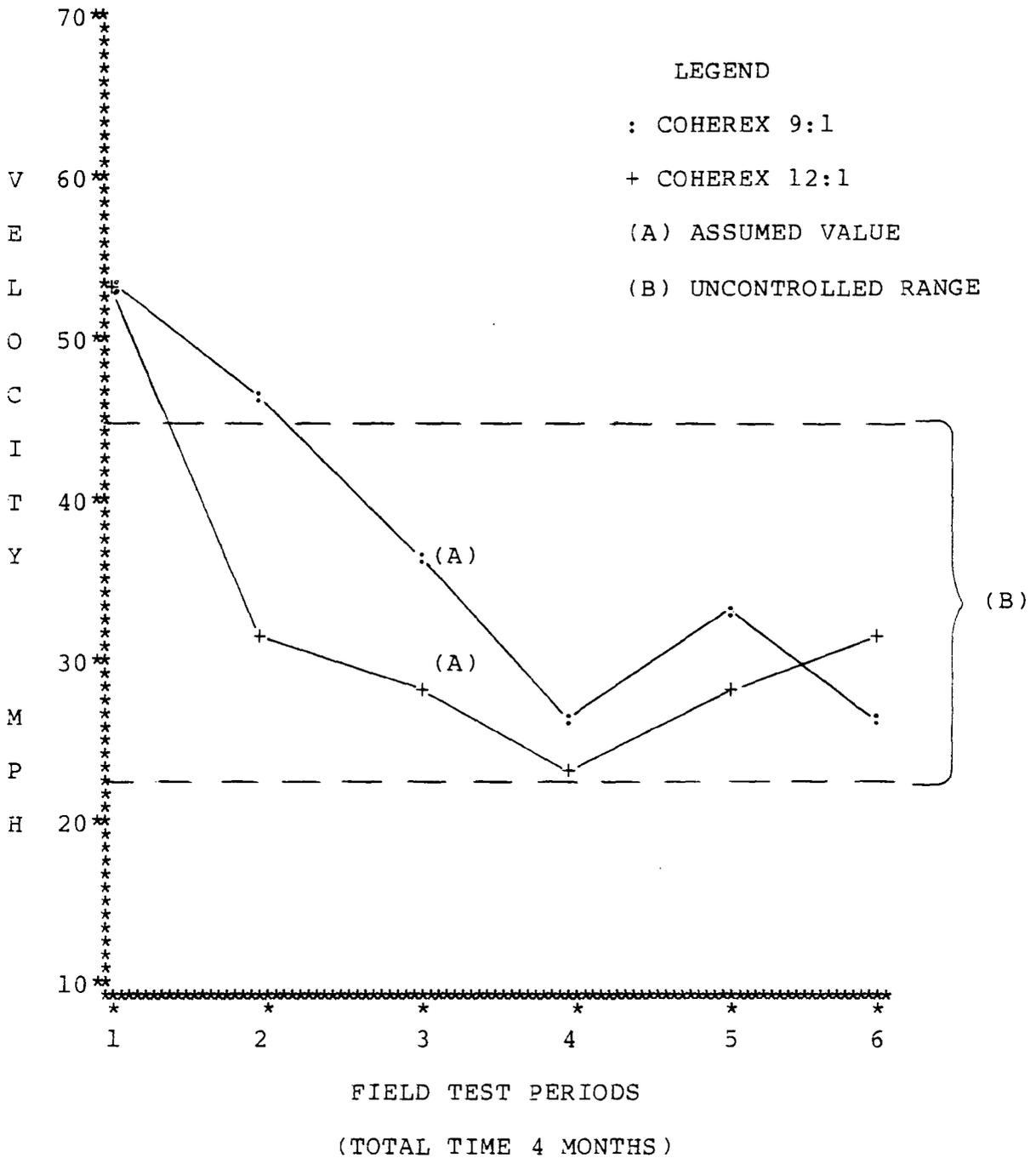


Figure F2.

LIGNOSULFONATE  
WIND EROSION THRESHOLD VELOCITY OVER TIME  
(VELOCITY @ 10 METER HEIGHT)

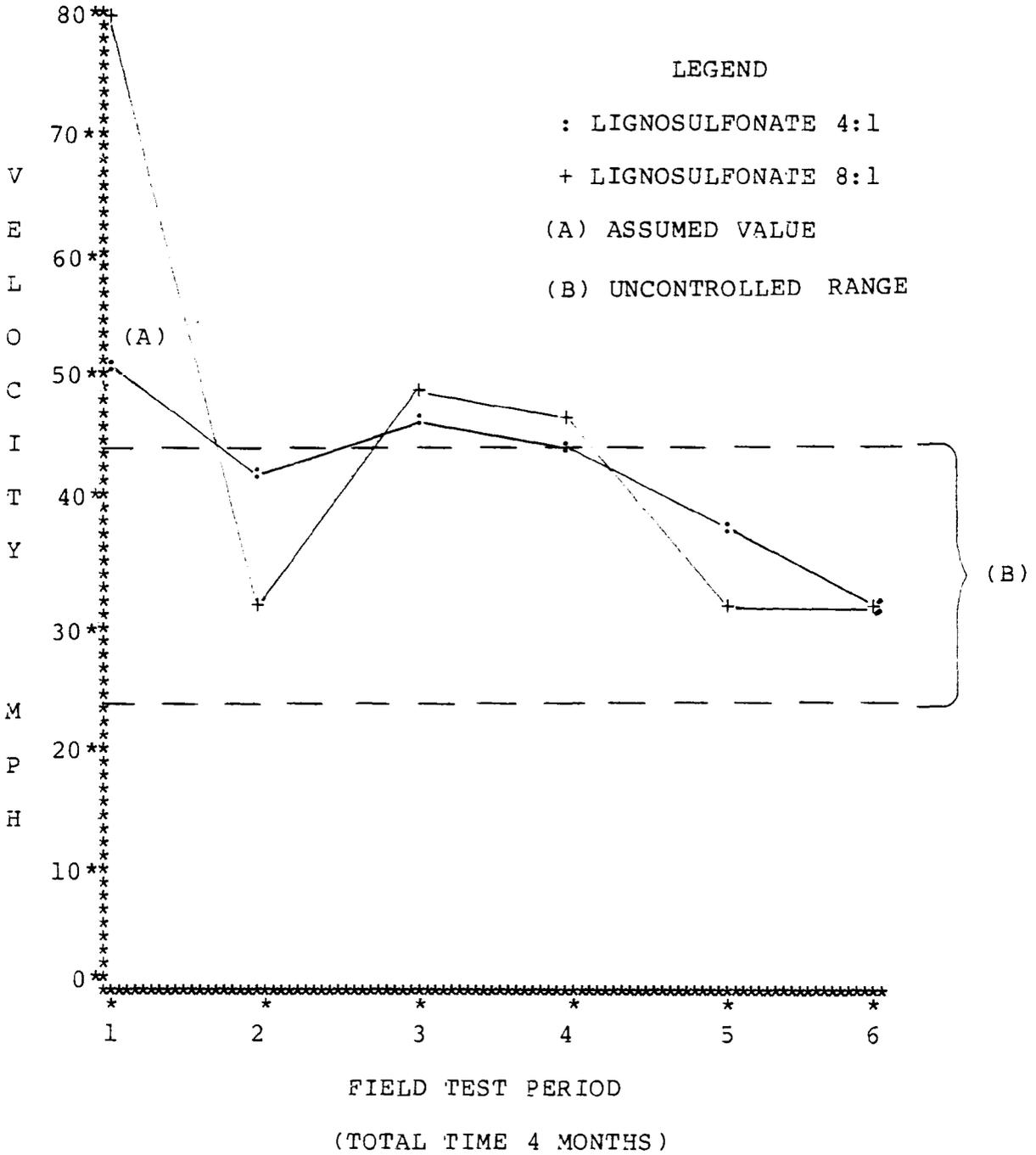


Figure F3.

NALCO 655 & 656

WIND EROSION THRESHOLD VELOCITY OVER TIME

(VELOCITY @ 10 METER HEIGHT)

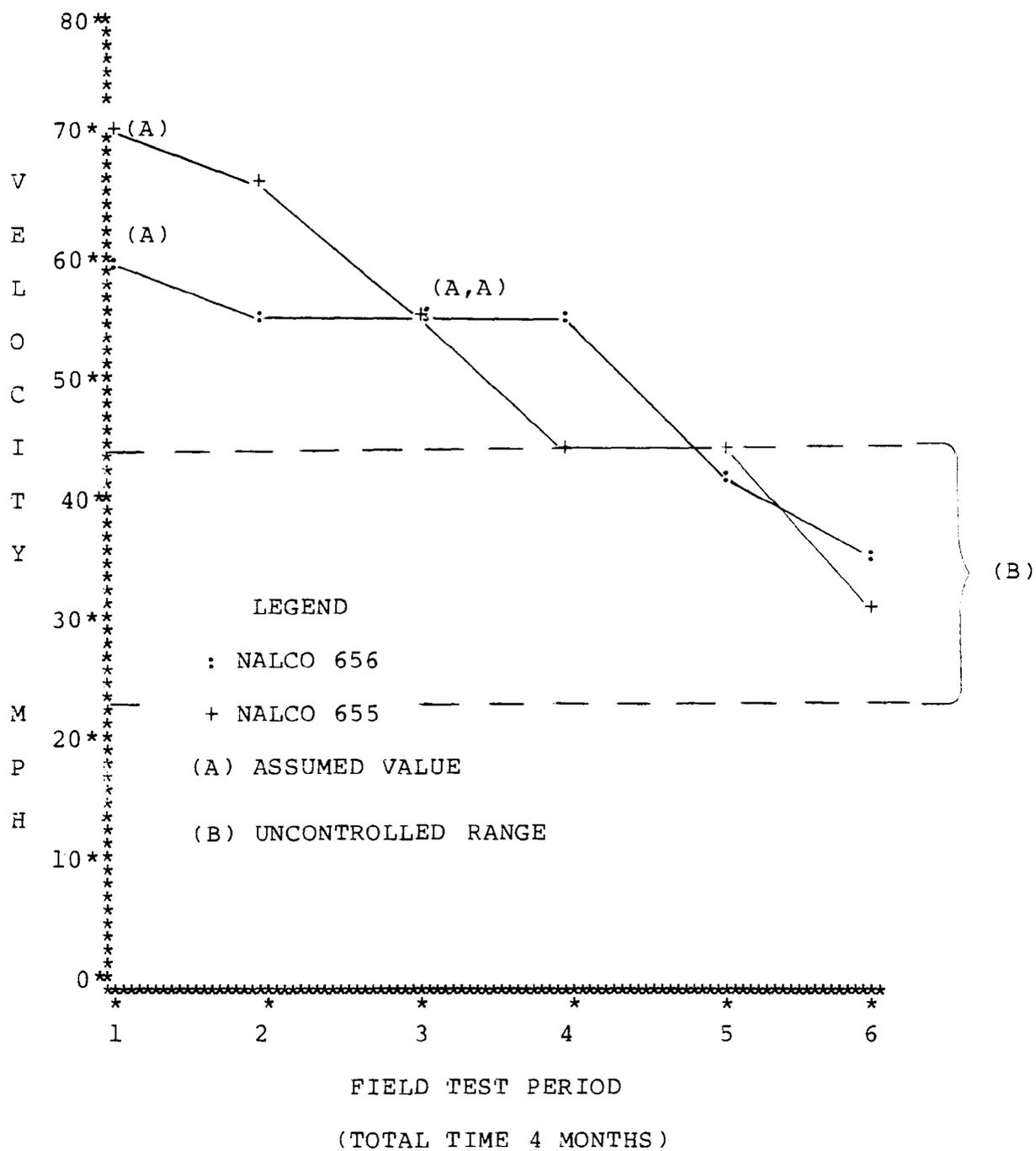
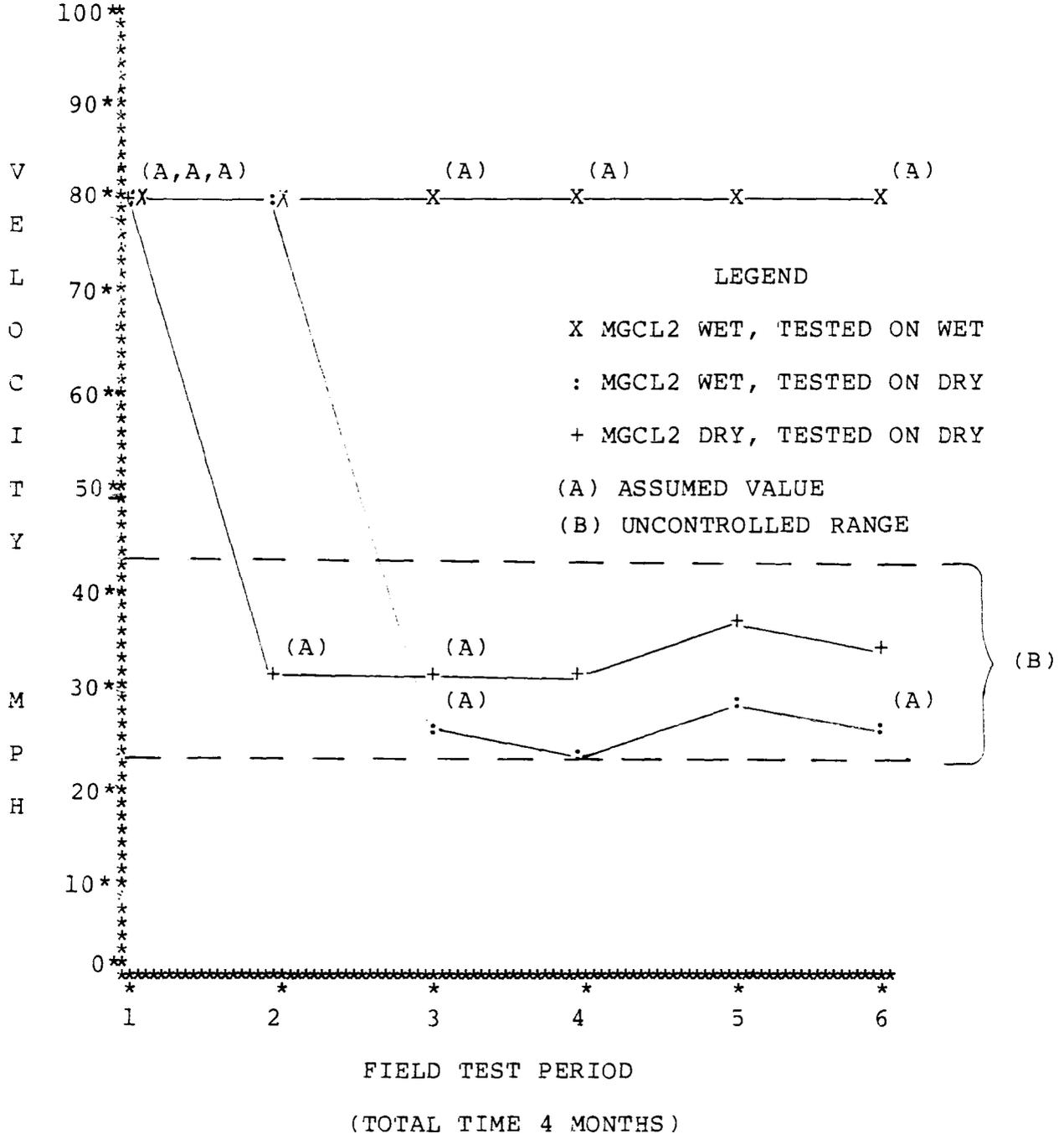


Figure F4.

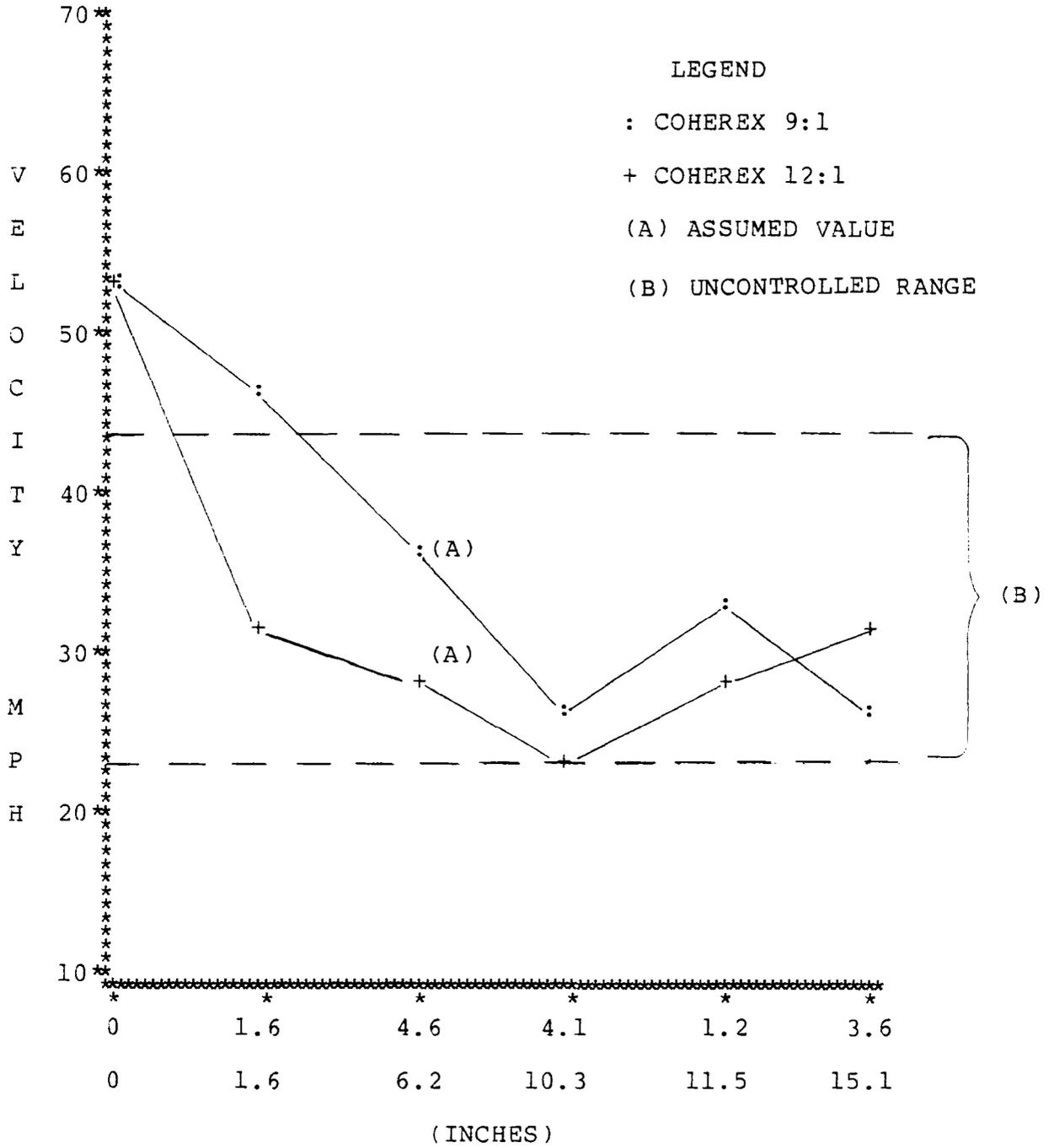
MAGNESIUM CHLORIDE (MGCL<sub>2</sub>)  
 WIND EROSION THRESHOLD VELOCITY OVER TIME  
 (VELOCITY @ 10 METER HEIGHT)



APPENDIX G. EFFECT OF RAINFALL ON THRESHOLD VELOCITY: 10 METER  
HEIGHT

Figure G1.

COHEREX  
 EFFECT OF RAINFALL ON THRESHOLD VELOCITY  
 (VELOCITY @ 10 METER HEIGHT)

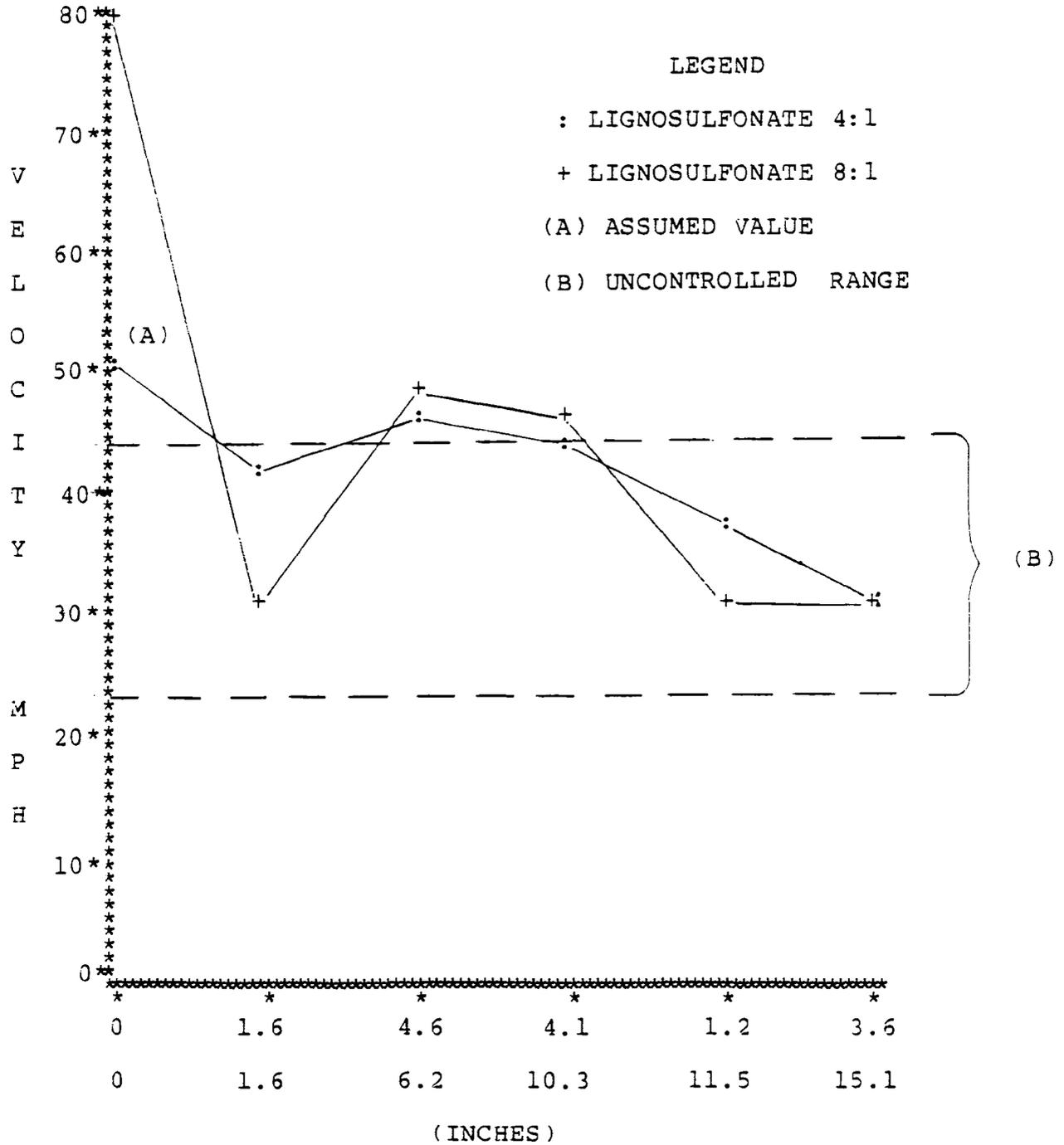


FIRST ROW: RAINFALL SINCE PREVIOUS TEST PERIOD

SECOND ROW: CUMULATIVE RAINFALL

Figure G2.

LIGNOSULFONATE  
 EFFECT OF RAINFALL ON THRESHOLD VELOCITY  
 (VELOCITY @ 10 METER HEIGHT)



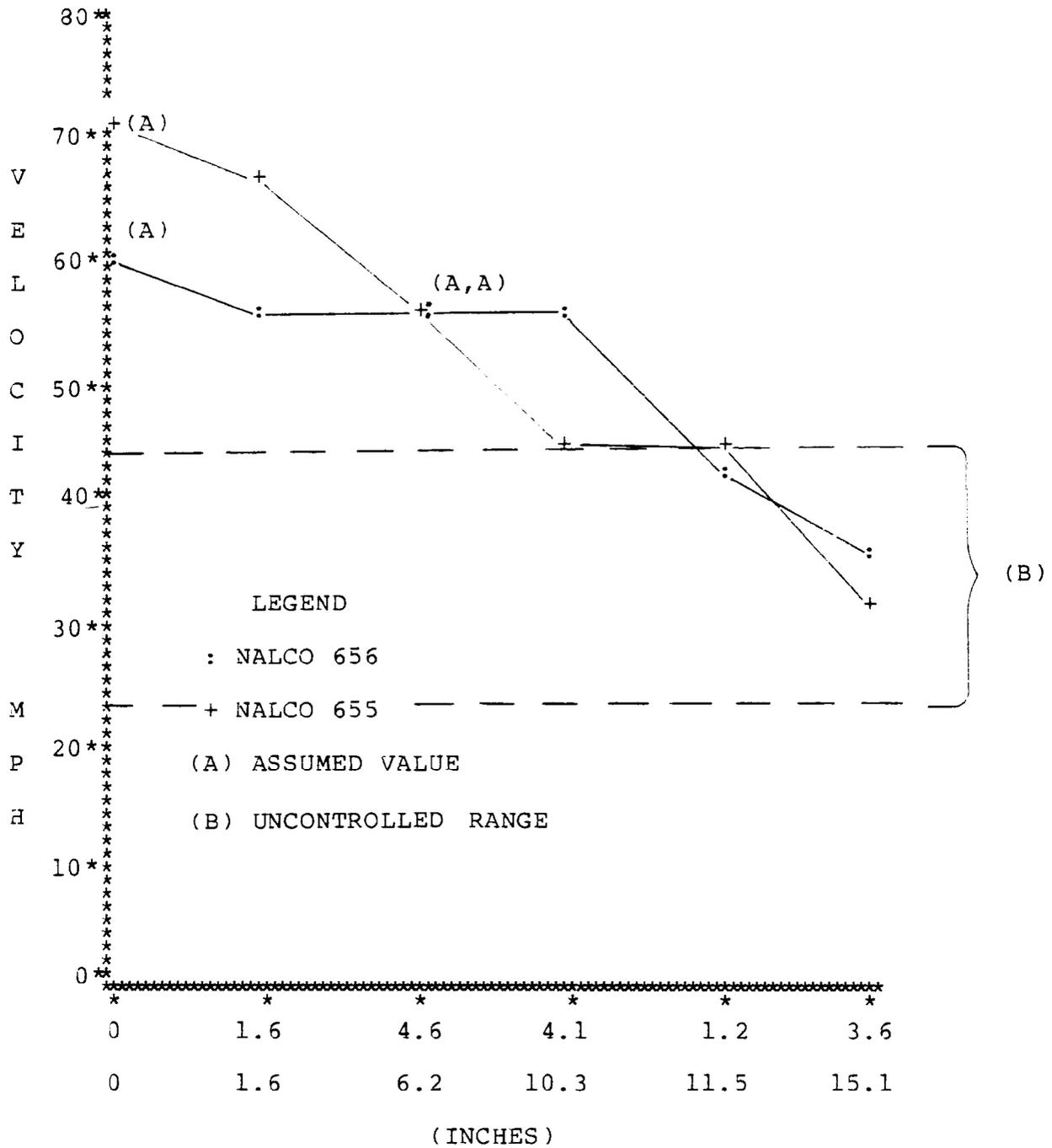
FIRST ROW: RAINFALL SINCE PREVIOUS TEST PERIOD  
 SECOND ROW: CUMULATIVE RAINFALL

Figure G3.

NALCO 655 & 656

EFFECT OF RAINFALL ON THRESHOLD VELOCITY

(VELOCITY @ 10 METER HEIGHT)

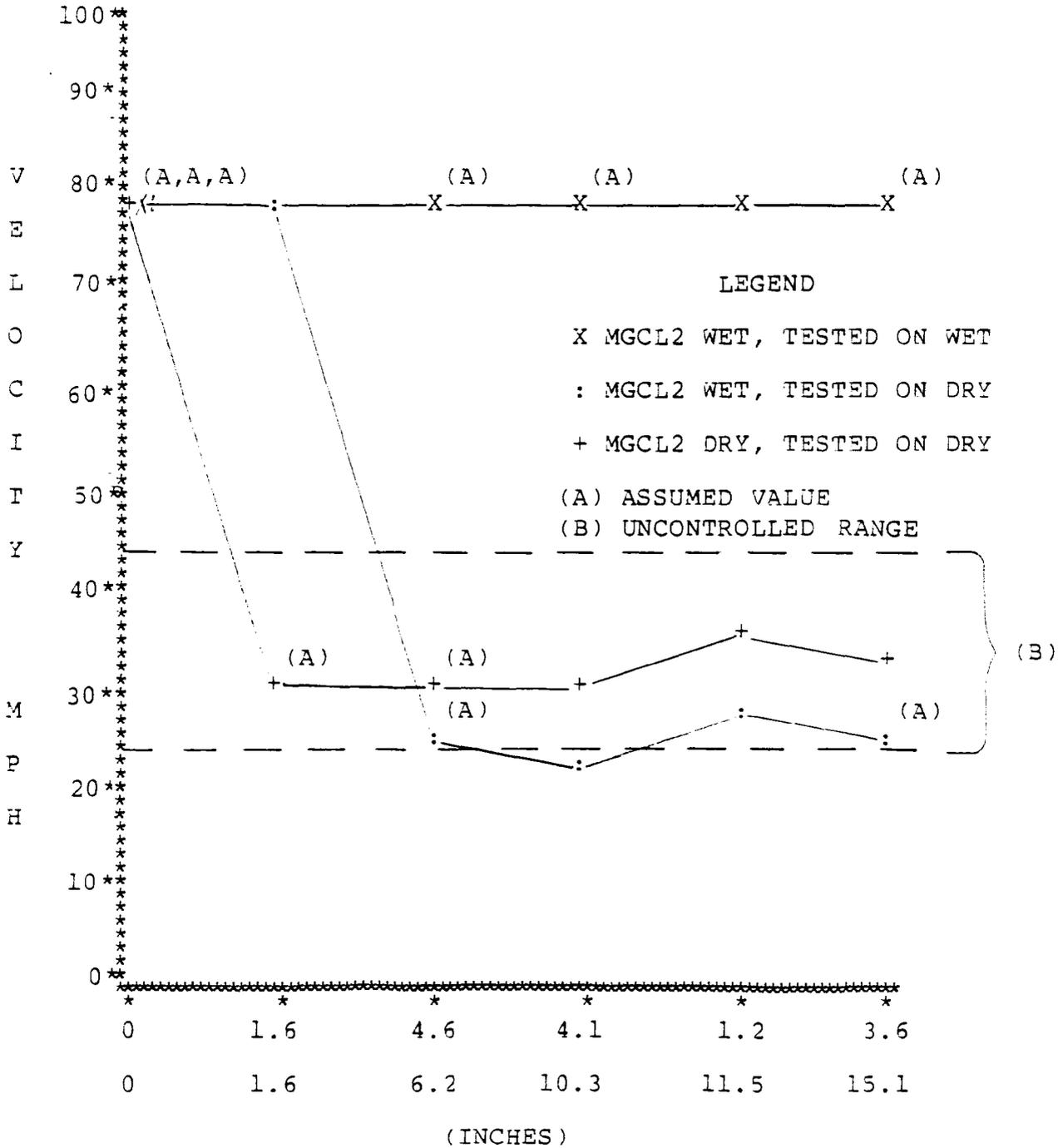


FIRST ROW: RAINFALL SINCE PREVIOUS TEST PERIOD

SECOND ROW: CUMULATIVE RAINFALL

Figure G4.

MAGNESIUM CHLORIDE (MGCL2)  
 EFFECT OF RAINFALL ON THRESHOLD VELOCITY  
 (VELOCITY @ 10 METER HEIGHT)



FIRST ROW: RAINFALL SINCE PREVIOUS TEST PERIOD  
 SECOND ROW: CUMULATIVE RAINFALL

APPENDIX H. RELATIONSHIP OF SILT CONTENT TO 10 METER HEIGHT  
THRESHOLD VELOCITY

Figure H1.

TACONITE TAILINGS  
SILT CONTENT VS. WIND EROSION THRESHOLD VELOCITY  
(VELOCITY @ 10 METER HEIGHT)

