INTERNAL REPORT

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EROSIONAL STABILITY OF WASTE ROCK

BATTERS UNDER SIMULATED RAINFALL:

REPORT ON PROGRESS, JANUARY 1990

Prepared by: S. J. Riley, Macquarie University

The Supervising Scientist for the Alligator Rivers Region has research, supervisory and co-ordination responsibilities related to effects on the environment and uranium mining in the Alligator Rivers Region and research and supervisory responsibilities related to effects on the environment of non-uranium mining in a conservation zone declared within the Region.

Supervising Scientist for the Alligator Rivers Region

REPORT ON PROGRESS

WASTE ROCK DUMP

EROSION STUDY

RANGER URANIUM MINE

NORTHERN TERRITORY

Prepared for

THE ADVISORY COMMITTEE

THE OFFICE OF THE

SUPERVISING SCIENTIST

S.J.Riley
School Earth Sciences
Macquarie University
NSW 2109

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EXECUTIVE SUMMARY

1. Development of the rainfall simulator has reached the stage at which nozzles are being tested.

2. Modeling using USLE and ANSWERS suggests erosion rates of the order of 2 to 4 tonnes/ha on the batters and 0.5-2 tonnes/ha on the cap for storms with intensities between 50 and 100mm.h^{-1}. The annual erosion rates are of the order of 10 and 2 tonnes/ha respectively.

3. Modeling suggests that rill/gully erosion is the most significant erosion process and the one likely to lead to breaching of the protective cap of the waste rock dump.

4. The monitoring equipment is largely installed, if somewhat behind schedule, and monitoring is underway.

TABLE OF CONTENTS

1. PROGRESS TO DECEMBER 1989

The progress of the project to December 1989 is:

i. A research assistant (Fergus Hancock) has been appointed and is working on the rainfall simulator.

ii. Two sets of nozzles for the rainfall simulator have been tested. Details are attached in the Section in this report on the rainfall simulator. A simulator after the style of the Colorado State University Rainfall simulator will be used. Other styles are not flexible enough for the project and would be too costly to construct.

iii. Preliminary modeling of erosion on the waste rock dump has been undertaken with USLE and ANSWERS. Details are given in the Section on modeling. Modeling indicates the significance of rill and gully erosion processes.

iv. The monitoring equipment is largely installed and the program of monitoring will be fully operational by the end of December. See section on monitoring

v. It was necessary to install a third set of instrumentation as part of the monitoring program.

vi. A preliminary model of the hydrology and erosion of the waste rock dump has been developed, as detailed in this report.

2. MONITORING

The monitoring program as outlined in the DRAFT document on monitoring has largely been instituted. Some problems were experienced and the cost of installation has exceeded the budget allocation.

2.1 Monitoring Stations

Three stations (consisting of computers, dataloggers, batteries, solar panels and electronic protection from lightning) were installed. The original plan to tie the CAP and BATTER sites into the one monitoring station was abandoned when the distance between them was judged to be too large (lightning strike problems). The EPSON PX-8 computers were running at too high a temperature, and since a new datalogger and computer had to be purchased for the third station it was decided to purchase the same computers (Toshiba 1000) for the other two stations. PX-8 computers are out of production.

2.2 Problems

Several major problems were faced during the construction phase, not the least being the two month wait for the backhoe, the need to purchase all items from Darwin, the difficulty of installing several items of equipment in the waste rock and natural site soils. The monitoring program did not seriously begin until early December Despite the late start to the monitoring program and the problems encountered sufficient information will be gained to make soundly based judgments on the nature of the erosion and hydrologic processes at the sites.

2.3 Installation

Details of the installation have been given in previous reports and are as set out in principle in the DRAFT report on the monitoring program, with some variations in the location of equipment.

Surveying of the sites will be delayed until the middle of 1990 when EDM equipment will be returned from Macquarie Island.

2.4 Success of monitoring

Preliminary observations during two storms suggest that the equipment was functioning and that results would be significant. It appears that all monitoring equipment is indicating significant erosion and and insights are being gained into the hydrologic processes, ie. no effort has been wasted in installing equipment.

Table

Catalogue of instrumentation

Instruments	Sites			
	CAP	BATTER	NATURAL	FOURTH
	Instrument numbers and codes			
Raingauges	CRM 1 to 7	BRA 1-12	NRA 1-13	FRA 1-25
Piezometers	CPI 1 to 16	BPI 1 to 24	NPI t to 18	---
Tensiometers	CTN 1 to 6	BTN 1 to 8	NTN 1 to 6	---
Depth indicators	CDI 1 to 13	BDA 1 to 13	---	---
Splash traps			NSPL 1 to 9	---
Stemflow traps	----	----	NSF 1 to 20	FSF 1 to 18
Wash traps	CWT 1 to 3	BWT 1 to 4	NWT 1 to 4	---
Rill traps	CRT 1 to 3	BRT 1 to 3	---	---
Flume traps	COUTT, CTOPT	----	---	---

3. A CONCEPTUAL MODEL OF EROSION AND HYDROLOGY

Flume studies, disk permeameter measurements, and observations in trenches (see report for Oct-Nov field trip) suggest the following model for the hydrology and erosion at the waste rock dump and natural site.

This model has to be tested and must be considered preliminary at this stage. It will be developed as results from the monitoring program are assessed.

For the CAP the initial stages of development of the soils are as outlined by CSIRO (1989), ie. the weathering of the surface material and the vertical translocation of fine material to fill voids. Over time a relatively impermeable carapace develops on the cap, with a depth of several metres. The impermeable nature of the cap promotes runoff and a network of rills develop on slopes steeper than 2°. These rills are shallow and wide because the large, less weathered gravel and boulders promote energy dissipation and armour the beds. Rills will coalesce and there is likely to be a series of thresholds for increasingly deep and wider gullies. It is likely that erosion will not be high on the interrill areas. Gully erosion will increase downvalley as catchment areas increase. The sequential development of fine grained sediment by weathering processes and its stripping during the wet season by surface erosion will lead to the continued lowering of the surface until a resistant lag gravel develops (as suggested by Cull and East).

For the BATTER the steep slope maintains a relatively porous material at the surface. Interflow is significant and removes fines that may accumulate in the upper surface, so voids never fill. The hydrology of the slope is dominated by both overland flow and interflow, with return flow concentrating water and leading to the development of rills. Rills are arranged in a trellis or parallel pattern and tend to coalesce only at the base of the slope. The length of the batter will largely control the extent to which rills develop and the porosity of the material will govern the width and depth of the rills/gullies that evolve. Some changes in batter slope geometry can be expected because the development of saturated zones at the base of the slope, probably of a dynamic nature, will lead to high porewater pressures and consequent reduction of slope stability. The final gradient of lower slopes will be a function of the shear strength of the batter material and the deposition of material eroded from up-slope. A general retreat of the slope into the cap may occur over time as a result of the development of the hydrology and morphology of the slope. Both interrill erosion and rill erosion will be much more significant on the batter than on the cap.

On the NATURAL slope infiltration rates are high and the soil fabric is highly porous. The protection of the slopes by vegetation imparts a high degree of stability. The monitored slope is of low gradient, between 5 and 10°, which suggests that the stable slopes of the batter may develop towards this gradient. Bioturbation appears to be hydrologically significant but observations do not suggest that it is significant in erosion. However, the site is not densely populated with termite mounds and the termite contribution to erosion may not be as high as that documented elsewhere (See DRAFT monitoring proposal). Rills are likely to be broad and shallow. Vegetation cover, binding roots, and well structured soil contribute to the low level of rill erosion. Interrill erosion is small, although it may be significant when the site is burnt.

4. RAINFALL SIMULATOR

The Colorado State University design for a rainfall simulator, as detailed in the proposal for the research program, has been chosen. All other systems are cumbersome, expensive to built, demand high levels of technical assistance, and would not be flexible enough for the conditions.

Tests at Macquarie have involved the measurement of raindrop size distribution, assessment of the effect of different pressures on drop size, rainfall pattern and area covered, and the measurement of the changes in rainfall characteristics with different sprinkler heights. Conclusion from these studies are:

i) drop sizes approximately equal to those of natural rainfall are achieved at low pressures (<1.5bar)
ii) square pattern nozzles are unsatisfactory and the circular patterns are preferred
iii) stand heights need to be at least 2 metres
iv) wind has a significant effect on the pattern of rainfall.

Some problems have been experienced in finding a site that is wind-free for the testing of rainfall patterns.

Rainfall intensities of the order of 50-100mm.h^{-1} have been achieved for each nozzle

3/4"nozzles appear to be the best for the study, delivering the right quantity of rainfall at the lower pressures over radii of 2-4m. It appears that a hexagonal pattern of sprinklers, spaced approximately 6-8m, will minimise the overlap of rain areas. Ten spinklers should cover an area of 120-140m^2.

Coefficients of variation of the rainfall intensity of the order of 75% have been achieved within a 3m radius of the nozzles. This is low, but approaching the value of 80-90% commonly reported in the literature.

The lower pressures of the nozzles means that pipe system design and pump types will not be a problem and high pressure hose and pumps will not be required.

Diagrams illustrating some of the results of the rainfall simulator are attached

5. MODELING SOIL EROSION

The research program required the modeling of the waste rock dump using the KINEROS and ANSWER models. Both models are event based and the synthetic rainfall series has not been produced. Neither model gives annual erosion values. As annual erosion rates are needed the USLE model was used in the in the place of KINEROS. ANSWERS includes USLE parameters (K and C) in the estimation of the erodibility of the surface materials. Continuity is thereby maintained between the two models (USLE and ANSWERS).

USLE is designed to assess the erosion rates of slopes, not catchments. For this reason, ANSWERS was not applied to the CAP and BATTER catchments of the waste rock dump. It was applied to the same hypothetical slopes that the USLE used.

5.1 USLE ESTIMATES

The Universal Soil Loss Equation (USLE) forms the basis of several soil erosion prediction models and has been used to predict soil erosion from mine rehabilitation areas. Whilst there are problems with its use, these problems are no greater than those faced when applying other erosion models. The USLE provides a means of assessing the significance of soil erosion on the rehabilitation structure. The reliability of the results is the subject of the monitoring program.

"The USLE is:

$$A = R.K.L.S.C.P$$

where

A is the computed soil loss per unit area

R is the rainfall and runoff factor, defined by the Rainfall erosion index EI_{30} where E is the rainfall energy and I_{30} the rainfall intensity for the most intense 30 minute period of the storm

K is the soil erodibility factor

L is the slope-length factor

S is the slope steepness factor

C the cover and management factor

P is the support practice factor

(Wischmeier and Smith, 1978)

The USLE was constructed from plot data and is primarily a method for assessing the magnitude of inter-rill erosion. The technique was not designed to apply to catchments or any slope where the dominant erosion process is gullying.

Hence, application of the model to the waste rock dump must be in the context of the soil loss from the slopes of the dump and not the soil loss from the catchment on the cap of the dump or from the catchment within which the dump resides. The model has no capacity to allow for the sediment delivery ratio, ie. sedimentation of material eroded from the hillslope is not incorporated in the model.

5.1.1 Rainfall factor

The USLE rainfall factor is a product of the rainfall energy and highest 30 minute intensity of each storm that contributes to the erosion. The EI parameter allows for rainfall detachment and transport capacity.

The moael was intended to predict annual erosion but it can be applied to events. However, it must be recognised that event based predictions will be less reliable than annual predictions of soil loss.

For this study the erosion produced by two storms is assessed as well as the annual erosion. The annual EI factor for Jabiru, as estimated by McFarlane and Clinnick (1984) is

750 t.m/ha/cm.cm/h

or

7500MJ.mm/ha.h.y

The two design storms used in this study are assumed to have one hour durations; storm A has an intensity of $50mmh^{-1}$ and storm B $100mmh^{-1}$. For simplification it is assumed that rainfall intensity is constant during the storms. Instead of the Wischmeier and Smith (1978) formula for calculating energy that of Rosewell (1986) is used, being derived from Australian data. This formula is:

$$E = 29.0(1-0.596e^{-0.04I}) \quad (J.m^{-2}.mm^{-1})$$

where I is the rainfall intensity of the storm

Storm A has an energy of 26.67 $J.m^{-2}mm^{-1}$ and B of 28.46$J.m^{-2}.mm^{-1}$

The EI values for these two storms are 670$MJ.mm.ha^{-1}.h^{-1}$ and

2800MJ.mm.$ha^{-1}.h^{-1}$

Storm	EI
annual	7500
A	670
B	2800

5.1.2 Soil erodibility

The K factor is estimated from a nomogram in which the percentage of silt and very fine sand, percent sand, percent organic matter, soil structure and permeability of the soil are the critical parameters.

The method of analysis of the sediments and the classification scheme for textural classes is important in the analysis. Specifically, silt and very fine sand is the fraction between 0.002 and 0.1mm, silt being 0.002-0.05mm and fine sand 0.05-0.1mm. The sand fraction lies within the range 0.1-2mm. The textural analysis should be undertaken only with mechanical dispersion since chemical dispersion biases the analysis towards the fine fraction.

Previous textural analysis of the waste rock dump and natural soil has involved chemical dispersion (eg. CSIRO 1989). The large size of the rocks also demands a large sample. For this study sediment samples of the order of 1.5-2kg were taken from sites on the waste rock dump and from the natural slope, allowed to stand in water for 7 days, and then wet sieved.

Sediment analysis from waste rock dump and natural site

Sieve size — Sample — Percentage coarse than

Site

Sieve size	a1 Tot	a1 <2mm	a2 Tot	a2 <2mm	b1 Tot	b1 <2mm	b2 Tot	b2 <2mm	c1 Tot	c1 <2mm	c2 Tot	c2 <2mm	d1 Tot	d1 <2mm	d2 Tot	d2 <2mm
	Percentage on fraction															
4mm	43	-	24	-	34	-	49	-	44	-	56	-	41	-	43	-
2mm	57	0	34	0	47	0	62	0	63	0	70	0	55	0	55	0
1mm	70	30	46	18	57	19	70	21	72	24	77	23	63	18	65	22
0.063mm	97	93	99	98	91	83	95	87	96	89	98	93	99	98	99	98

where a and b are sample sites on the cap
c is the sample site on the batter
d is the natural sample site

CSIRO (1989) textural and C% results
(on fraction <2mm)

	203 Frac	203 Cum	212 Frac	212 Cum	208a Frac	208a Cum
2000-210	57		48		65	
210-20	24	57	24	48	26	65
20-2	6	81	10	72	3	91
<2	12	87	18	82	6	94
C%	.74		.46		.80	

Fac= percentage in fraction
Cum= percentage coarser than

There is a lack of silt-clay, even in the CSIRO samples (when an assumption is made about the percentage of gravel in the samples). Silt-clay is less than 28% of the <2mm fraction, and less than 15% of the total sample. The effect of chemical dispersion is significant.

The small differences between the waste rock sites and the natural soil sites suggest that weathering of the waste rock dump materials has rapidly reached the textural characteristics of the natural soils.

For this study it is assumed that the silt+fine sand, clay, coarse sand organic matter content of the waste rock dump materials is:

Texture	%
coarse sand	85
fine sand	5
silt	5
clay	5

This texture is assumed to be the same for the batter slopes and cap slopes.

The textural class of the material is assumed to be fine granular, because the majority of material is in the coarse sand, fine gravel fraction.

Disk permeameter infiltration rates on the cap are 20-40mm.h^{-1}, which is a moderate rate of infiltration, class 3 in the USLE, while the batter slopes have infiltration rates of 100-170mm.h^{-1}, which are classed as moderate to rapid, class 2 in the USLE, although the higher rates are class 1, ie. rapid.

5.1.3 Topographic factor.

The length of slope and slope angle vary across the rehabilitation structure. However, for this study the batter slopes are assumed to have the following characteristics:

length	100m
slope	20%

The cap slopes are assumed to be long and of low gradient. A typical slope, used in this study, is:

length	300m
slope	3%

Slopes are assumed to be rectilinear. Although many other slope lengths and geometries could be used, this preliminary modeling study is designed to indicate the general magnitude of the erosion problem, not to define the exact magnitude of erosion.

5.1.4 Support factor

It is assumed that there is no cultivation or contour ploughing of the slope and the up and down slope tillage option is chosen, since this will best represent the long term condition in which rills will develop.

P is assumed to be 1.

5.1.5 Cover factor

The C value for a construction site with crushed stone cover (Table 9 of Wischmeier and Smith, 1978) is assumed for the waste rock dump. This gives a C value of 0.05 which also accounts for vegetation cover. This value of C is conservative, it is more likely to be 2 or three times larger.

5.1.6 Calculation

The SCS NSW SOILOSS program (Edwards and Rosewell, 1988) is used for calculating the soil loss.

	Soil loss tonnes/ha		
	As specified	With infiltration class 4	With 10% clay and 10% fine sand
Batter			
Annual	8.2	26	33
A	0.7	23	
B	3.1	10	
Cap			
Annual	1.7	2.7	3.3
A	0.2	0.2	
B	0.6	1.0	

The soil loss predictions are low, the annual rate for the batter being equivalent to surface lowering of 1m/1000y (assuming a density of 1tonne.m^{-3}). Such soil loss rates are not significant in terms of the depth of the protective cap. The losses for individual, but large storms are also small and do not suggest that they will result in major degradation of the waste rock dump.

These predicted annual soil losses are higher than the natural rates estimated by Duggan (1988); she obtained denudation rates of the order of 10-50mm/1000y. Hence, while the waste rock dump's structural integrity will not be jeopardised by interrill erosion the receiving waters will have higher than background sediment loads.

The results are sensitive to the infiltration estimates, values doubling with a decrease in the assumed infiltration rate. The predictions are not sensitive to changes in the textures, as the fourth column shows (calculated assuming low infiltration rates ie. class 4).

The USLE predictions suggest that inter-rill erosion will not be significant in the degradation of the waste rock dump. However, this does not mean that rill and gully erosion will not be significant.

5.2 ANSWERS

USLE and ANSWERS differ in that the former is designed to predict gross sediment loads while the latter predicts total sediment loss. ANSWERS is a distributed model while the USLE is a lumped system approach, heavily relying on empirical results.

For this study a rill of length 20m, in the case of the batter slope, and 50m for the cap slope is assumed to run up the centre of the slope. The slope drains into the rill.

Values of the parameters adopted for this study are:

TP= 0.3
FP= 0.8
FC= 20.
A = 100
P = 0.65
DF= 200.
ASM=1.
K = 0.3
PIT=2
PER=0
RC= .3
HU= 10.
N = 0.075
C = 0.05
Channel width=1m
Channel roughness=0.04

The average soil loss, maximum erosion rate in rill, and maximum concentration of sediment load for the two sites for each of the rainfall events (A and B) is:

Site	Rainfall event	Average erosion	Rill erosion -maximum	Maximum conc discharge
		tonnes/ha	tonnes/ha	mg/L
Batter	A	.5	1.6	36000
	B	2	5	41000
Cap	A	0.4	0.9	30000
	B	1.5	3.2	54000

with C = 0.1

Cap	B	2.9	6.4	50000

The maximum sediment concentrations occur on the receding stage of the flow. At the peak of the hydrograph the concentrations are of the order of 1000-3000mg.L^{-1}. The peak sediment load would normal precede the peak of the hydrograph, representing the flushing of loose sediment from the catchment. The lagged peak sediment concentration may be a result of gully development (channel erosion).

The erosion rates for cells with a channel are averaged over the area represented by the grid element, which in this case is 100m^2. The actual erosion from the channel is 5-8 times larger than that calculated for the element containing the stream. The average erosion rate on the cap for storm B is equivalent to 0.2mm of stripping. In the cell with the highest erosion rate the incision of the channel is 3mm. Stream incision on the batter is approximatly 5mm.

A half hour storm with a rainfall intensity of 50mm.h^{-1} can be expected more than once a year. A one hour duration storm with 100mm.h^{-1} intensity is a 50 year event. Thus, the minimum annual rate of channel incision on the cap will be 1mm, and on the batter 2mm. At the very least gullies 1-2m deep will develop over the rehabilitation structure in a 1000 years. Since a conservative value has been adopted for the cover factor it is highly likely that gully incision and general lowering of the surface will be much greater than this initial analysis suggests.

The event based sediment yields predicted by ANSWERS are similar to those predicted by USLE, except when the infiltration factor is altered in the USLE. The distributed model suggests that the erosion is dominated by rill/gully erosion.

There is no merit in continuing the analysis by varying the parameters in ANSWERS. More detailed analysis of erosion with the model must await the analysis of the monitoring data. At that time sufficient data will be available to undertake optimisation of the parameters. A synthetic storm event series is also required in order to predict annual erosion rates with the model.

6. REFERENCES

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Rosewell,C and Edwards,K. 1988. SOILOSS. A program to assist in the selection of management practices to reduce erosion. Soil Conservation Service of New South Wales Technical Handbook No.11.

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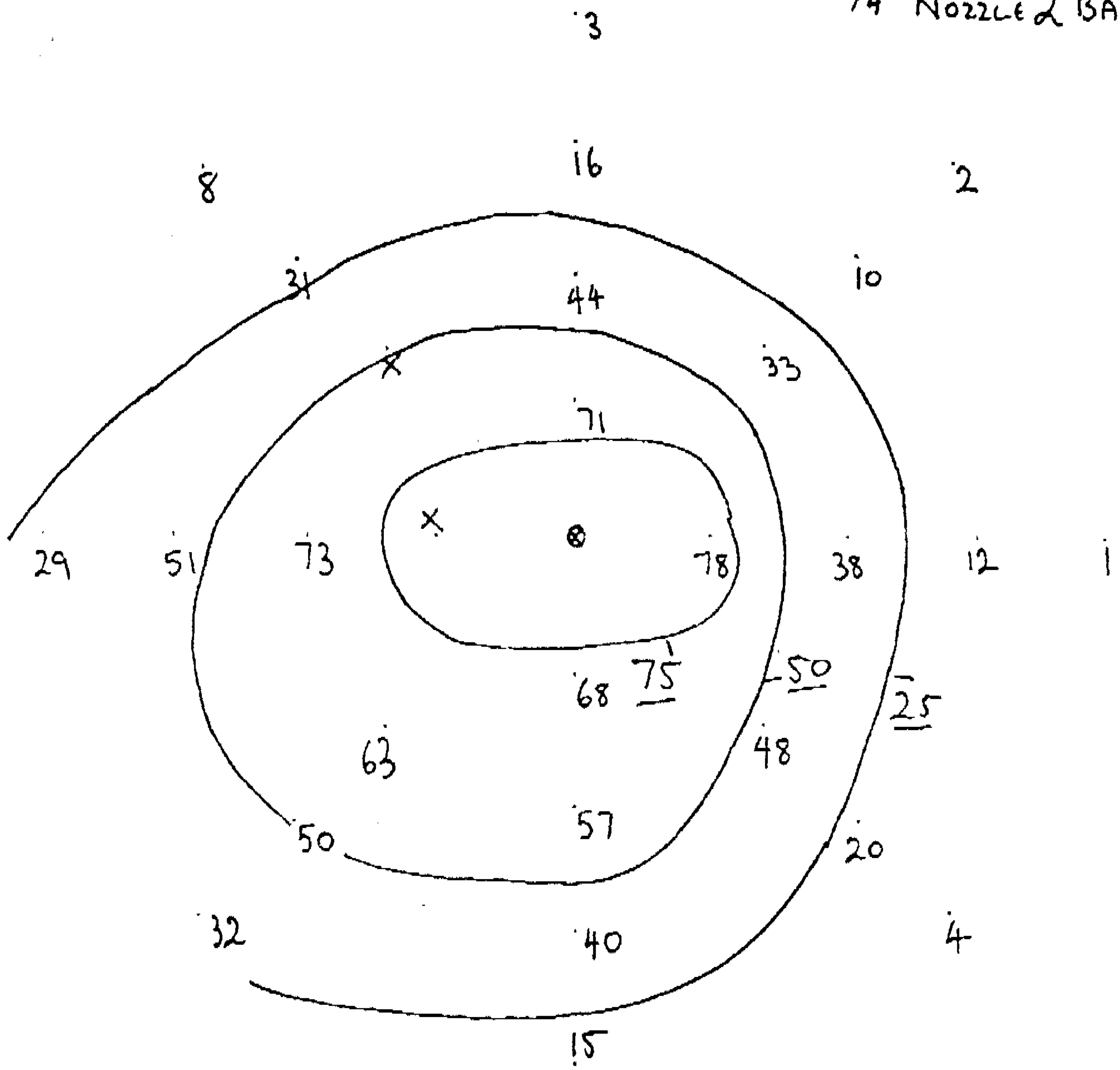
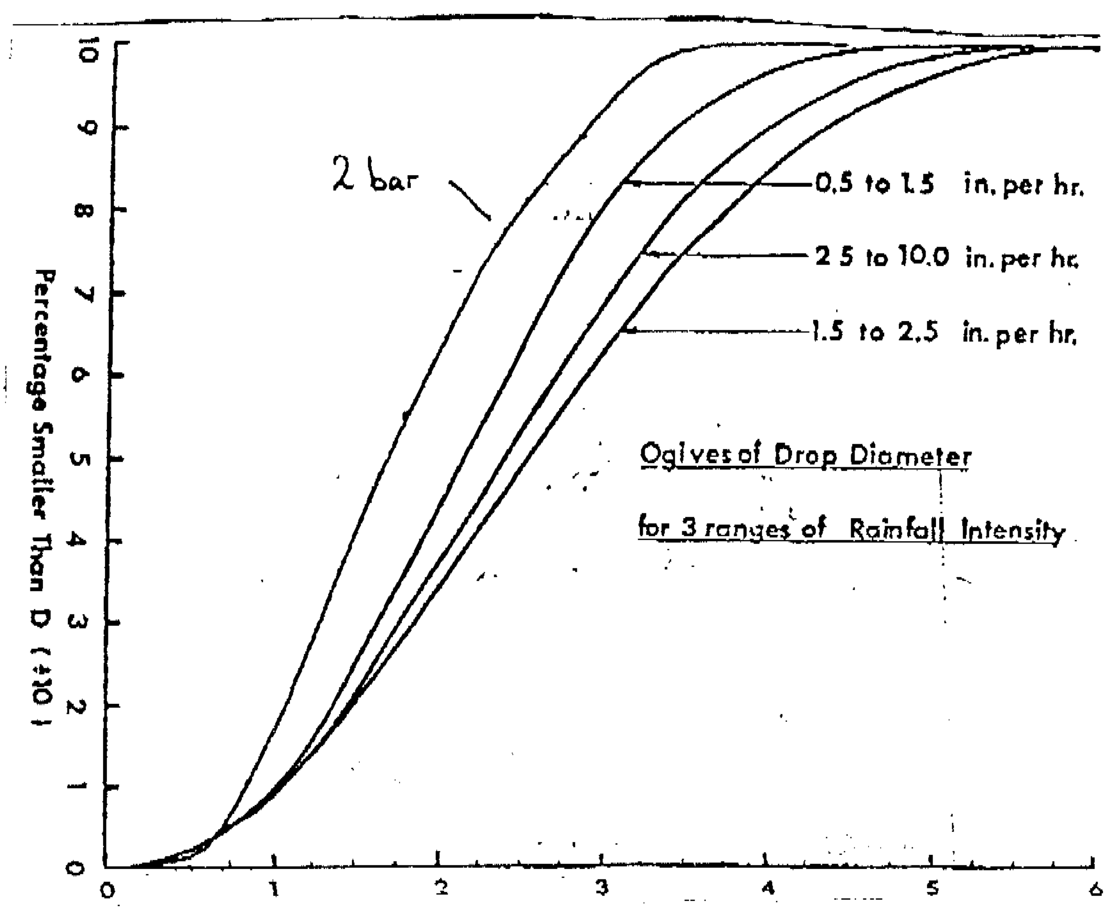
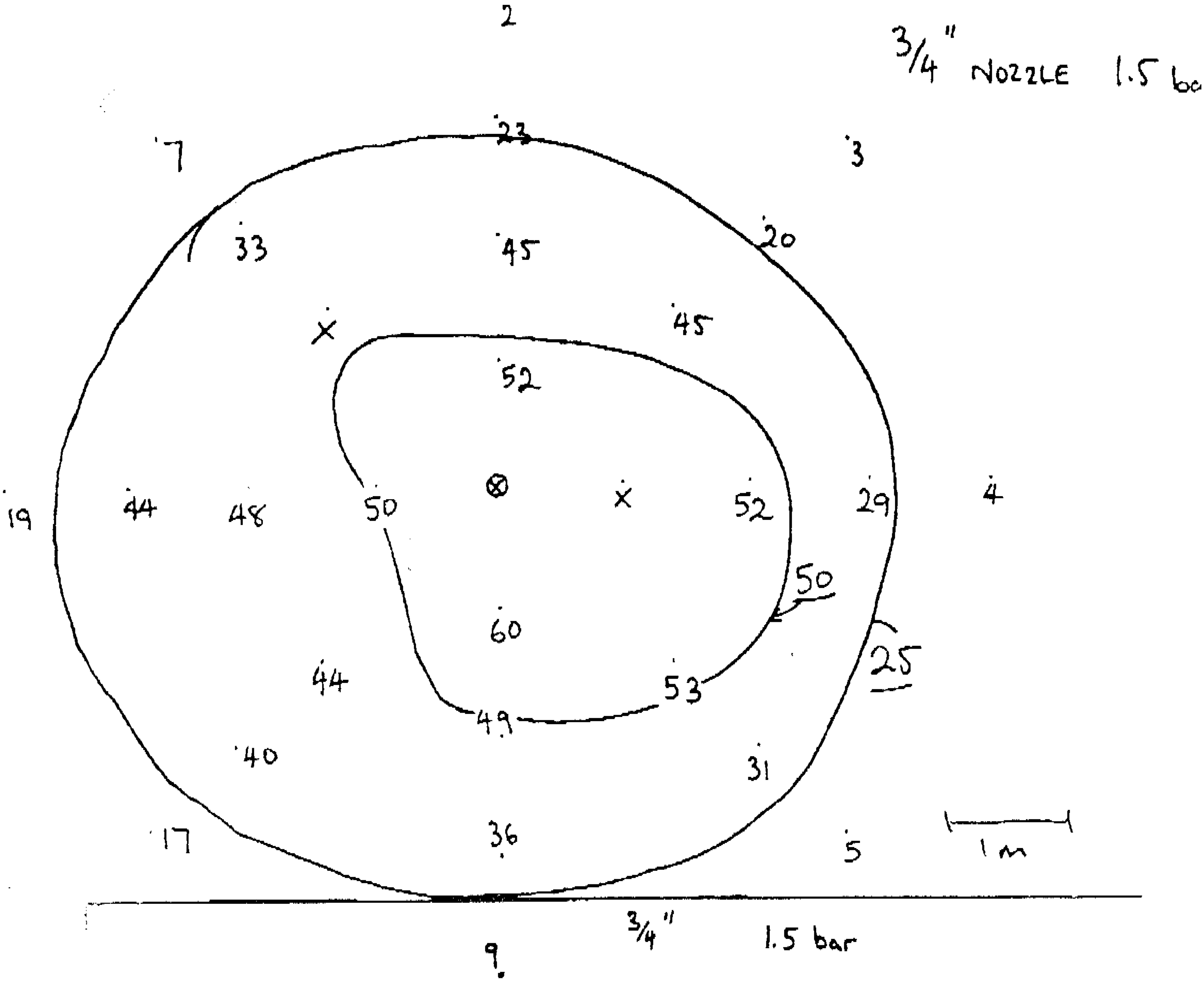
3/4" NOZZLE 2 BAR






3/4" NOZZLE 1.5 ba
2
7
23
3
33
45
20
45
52
19
44
48
50
52
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4
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44
53
49
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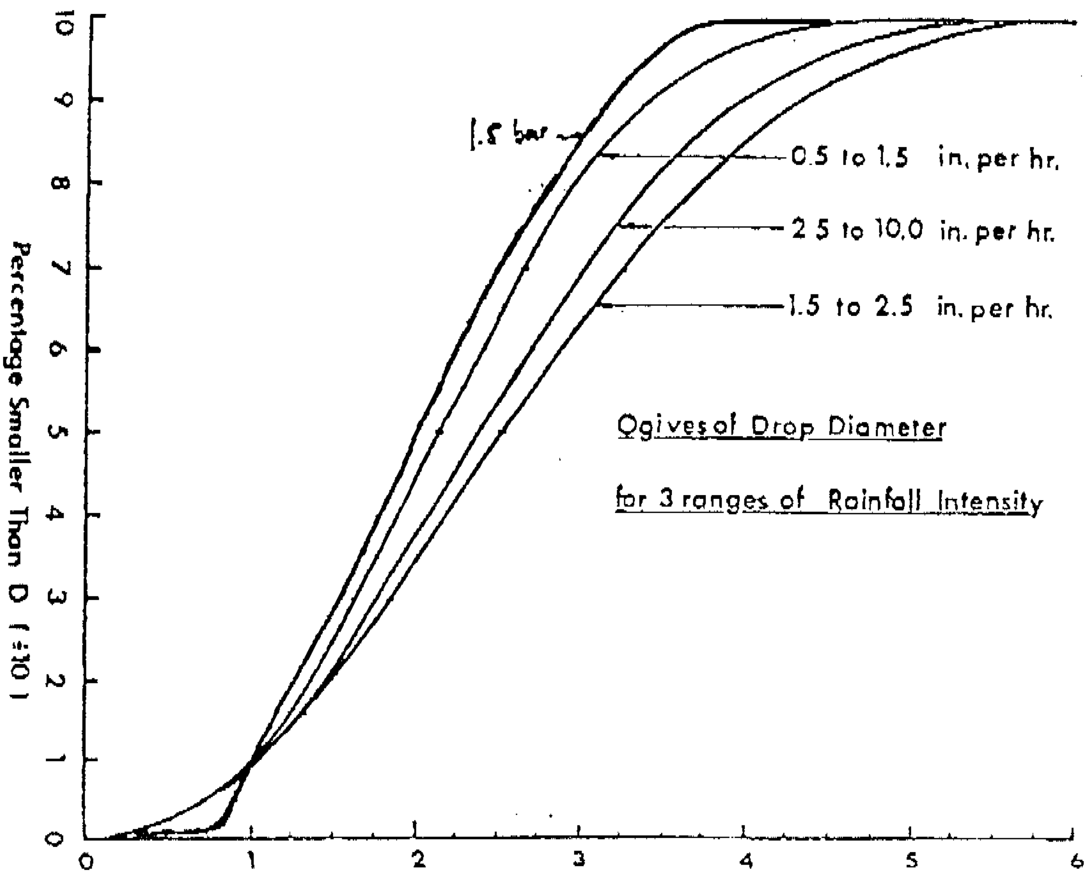
31
17
36
5
1m
3/4"
1.5 bar
9


1.5 bar
0.5 to 1.5 in. per hr.
2.5 to 10.0 in. per hr.
1.5 to 2.5 in. per hr.
Ogives of Drop Diameter
for 3 ranges of Rainfall Intensity
Percentage Smaller Than D (÷10)
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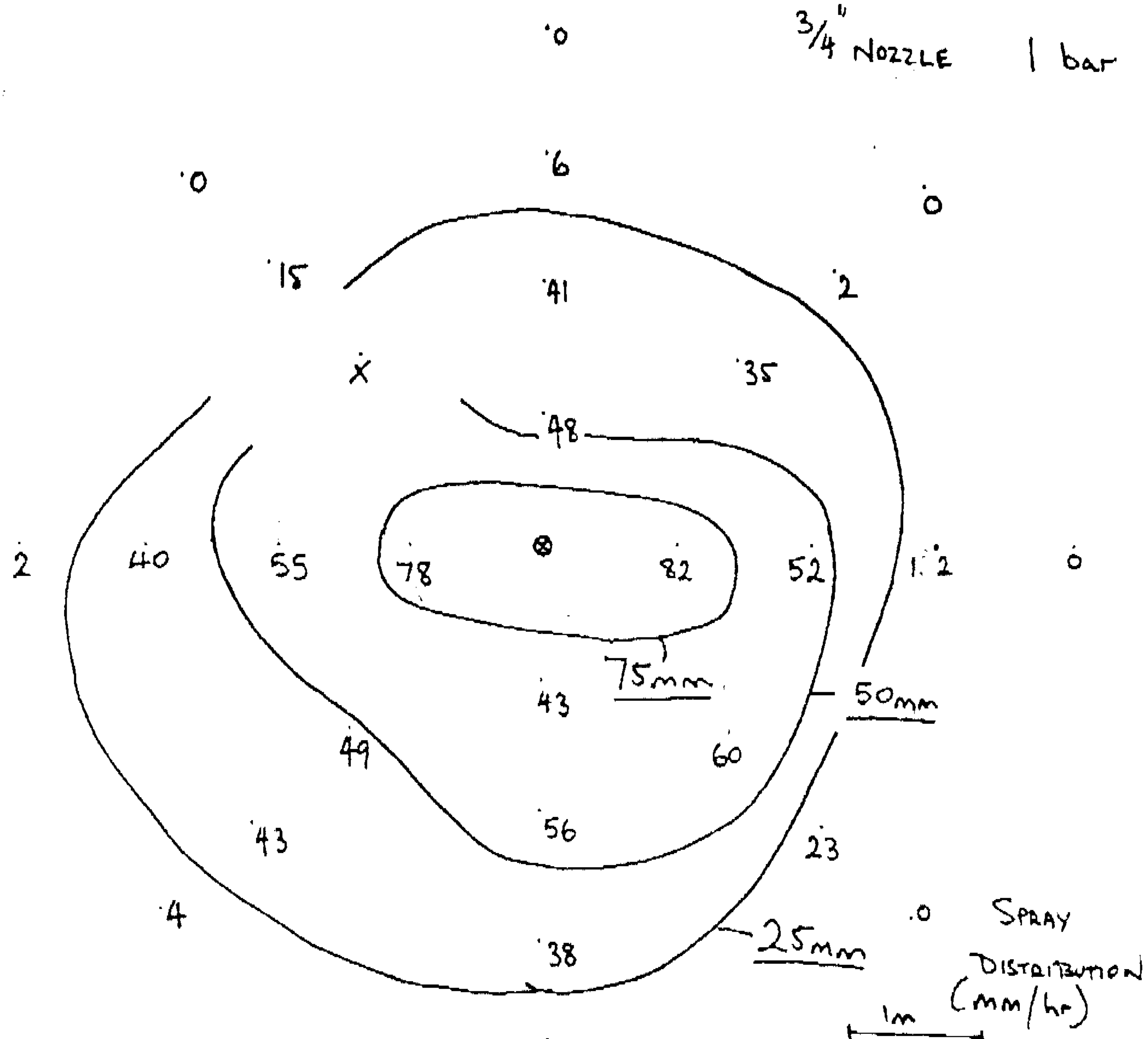
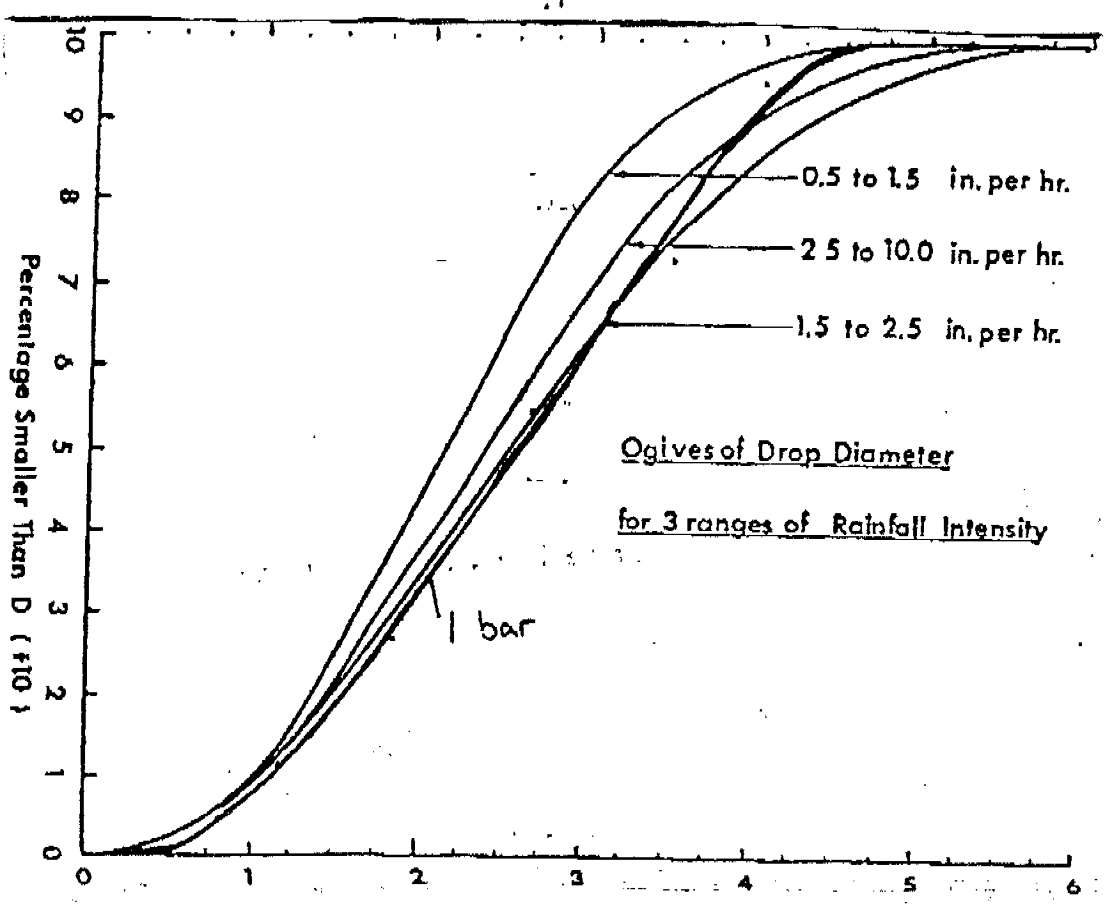
3
4
5
6
7
8
9
10



3/4" NOZZLE 1 bar
·0
·6
·0
·0
·15
·41
·2
X
·35
·48
2
40
55
78
⊗
82
52
1·2
·0
75mm
43
50mm
49
60
43
56
23
·4
·0
SPRAY DISTRIBUTION (mm/hr)
25mm
38
1m

4



0.5 to 1.5 in. per hr.
2 5 to 10.0 in. per hr.
1.5 to 2.5 in. per hr.
Ogives of Drop Diameter
for 3 ranges of Rainfall Intensity
1 bar
Percentage Smaller Than D (×10)
0
1
2
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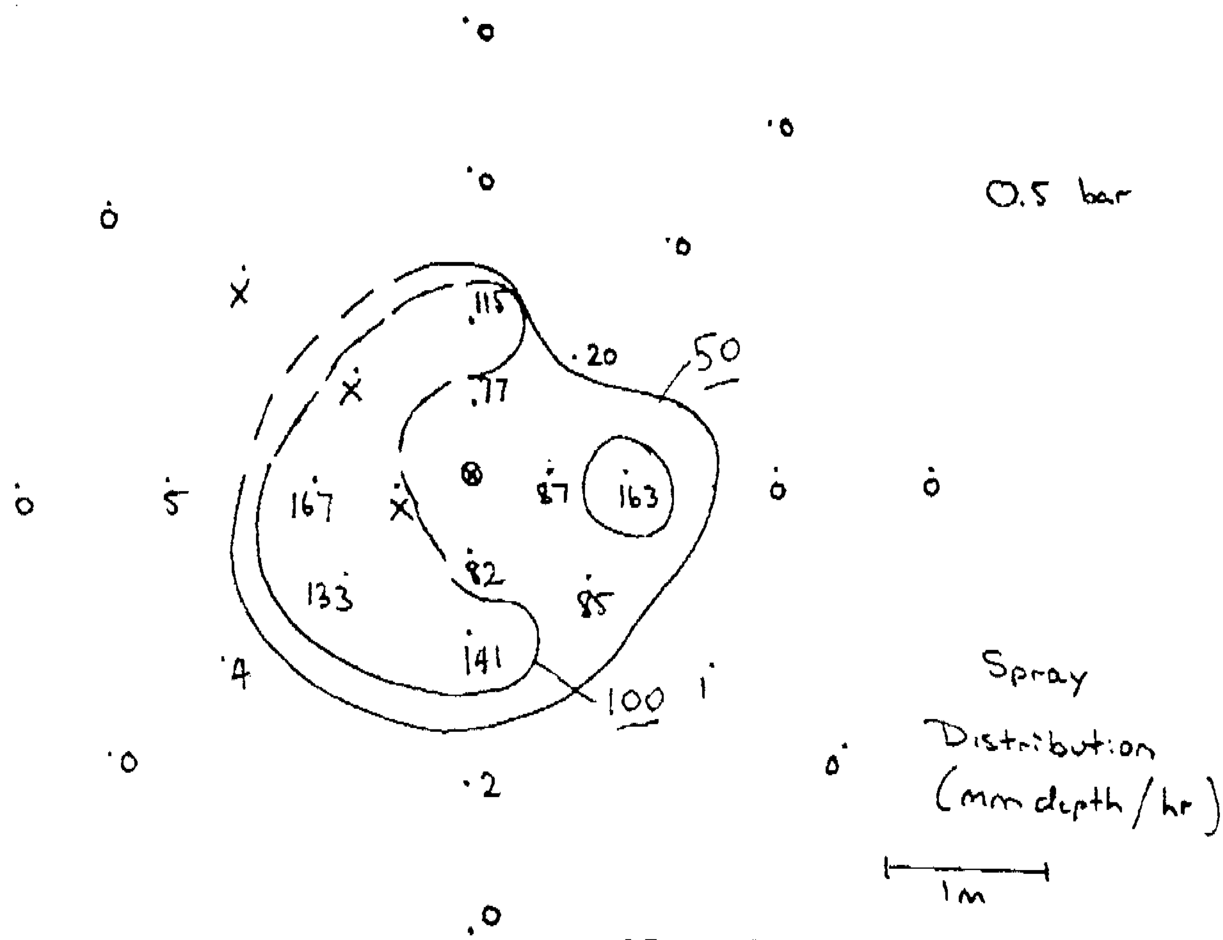
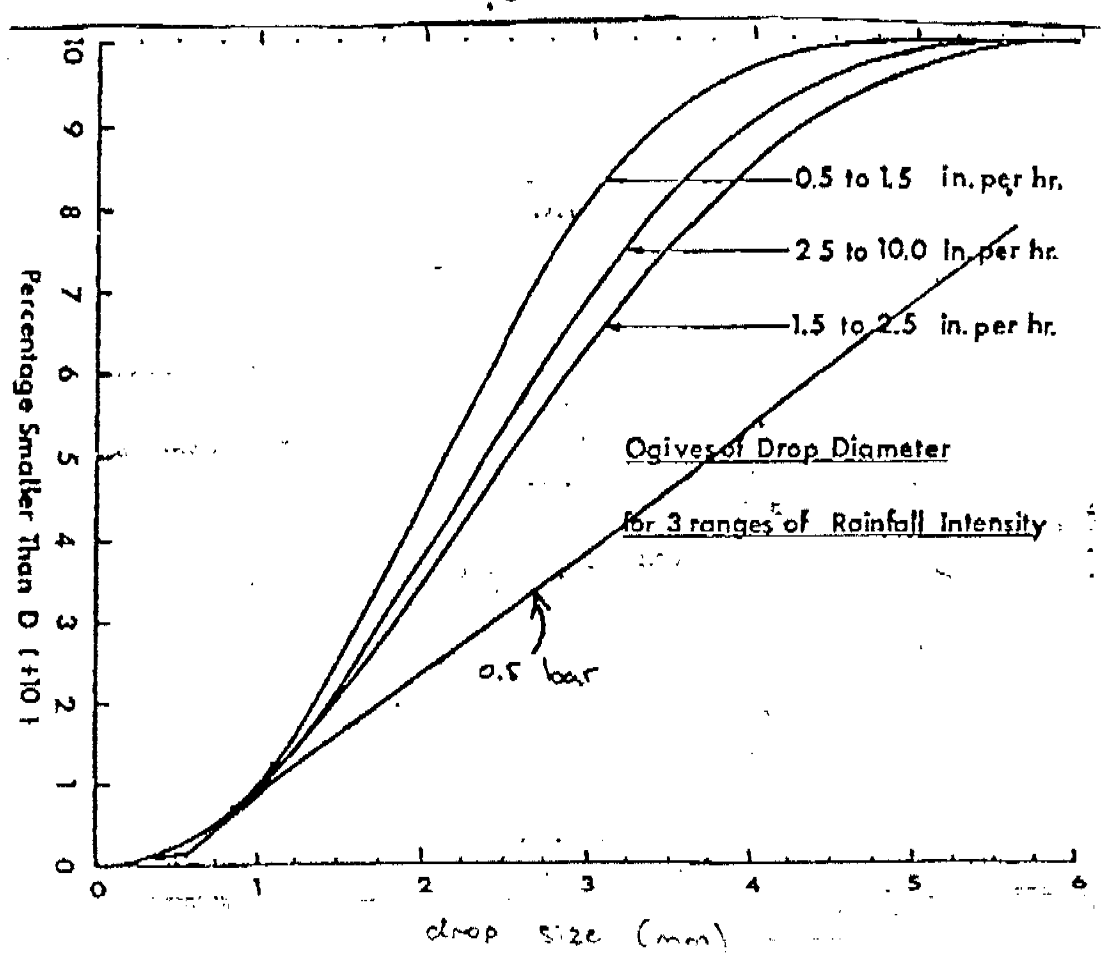
6

3/4" Fullcone Nozzle 0.5 bar

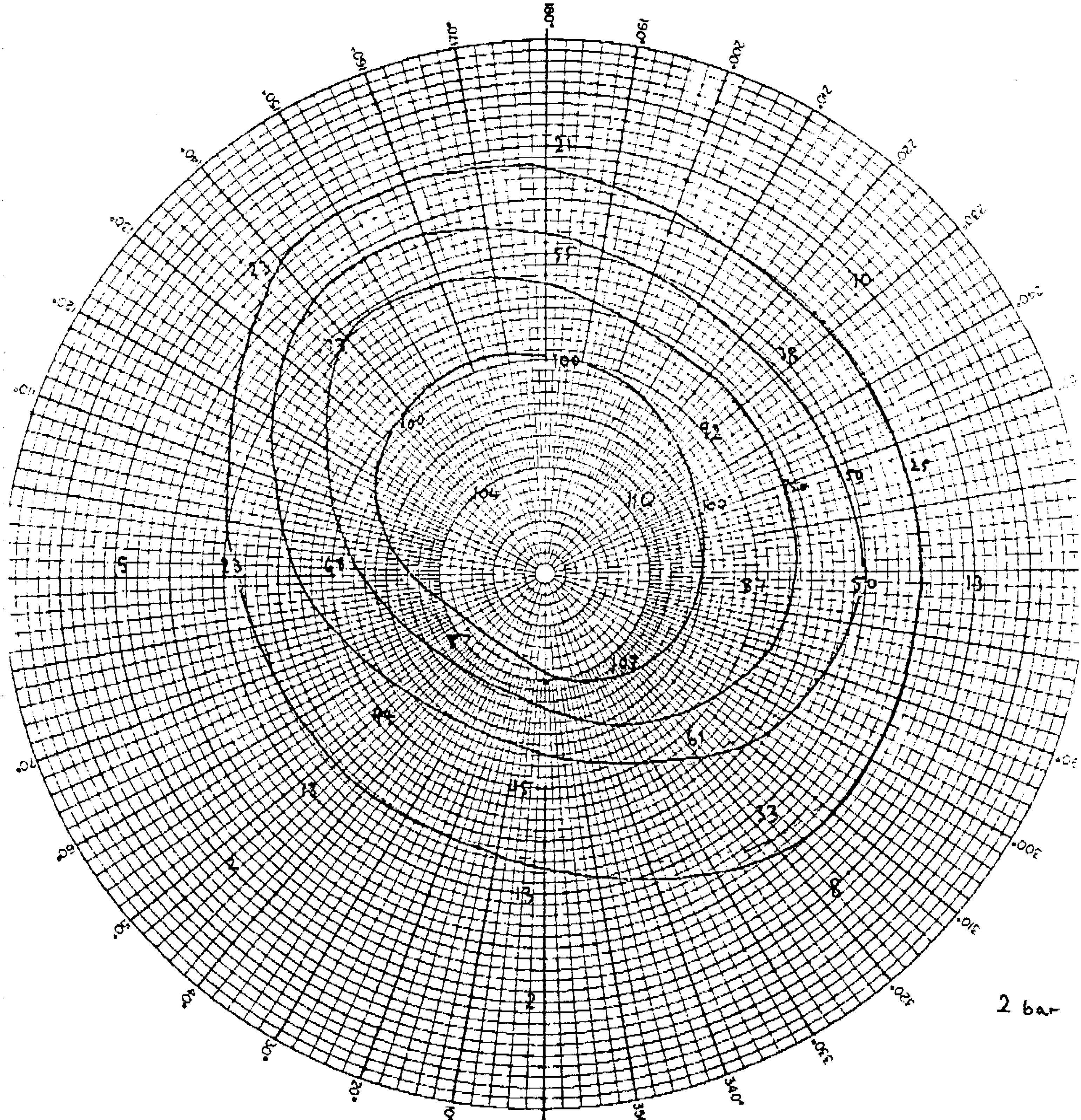




3/4" NOZZLE 3m HEIGHT (mm depth / hr)

DU 2m 77%

3m 57% - 2 bar



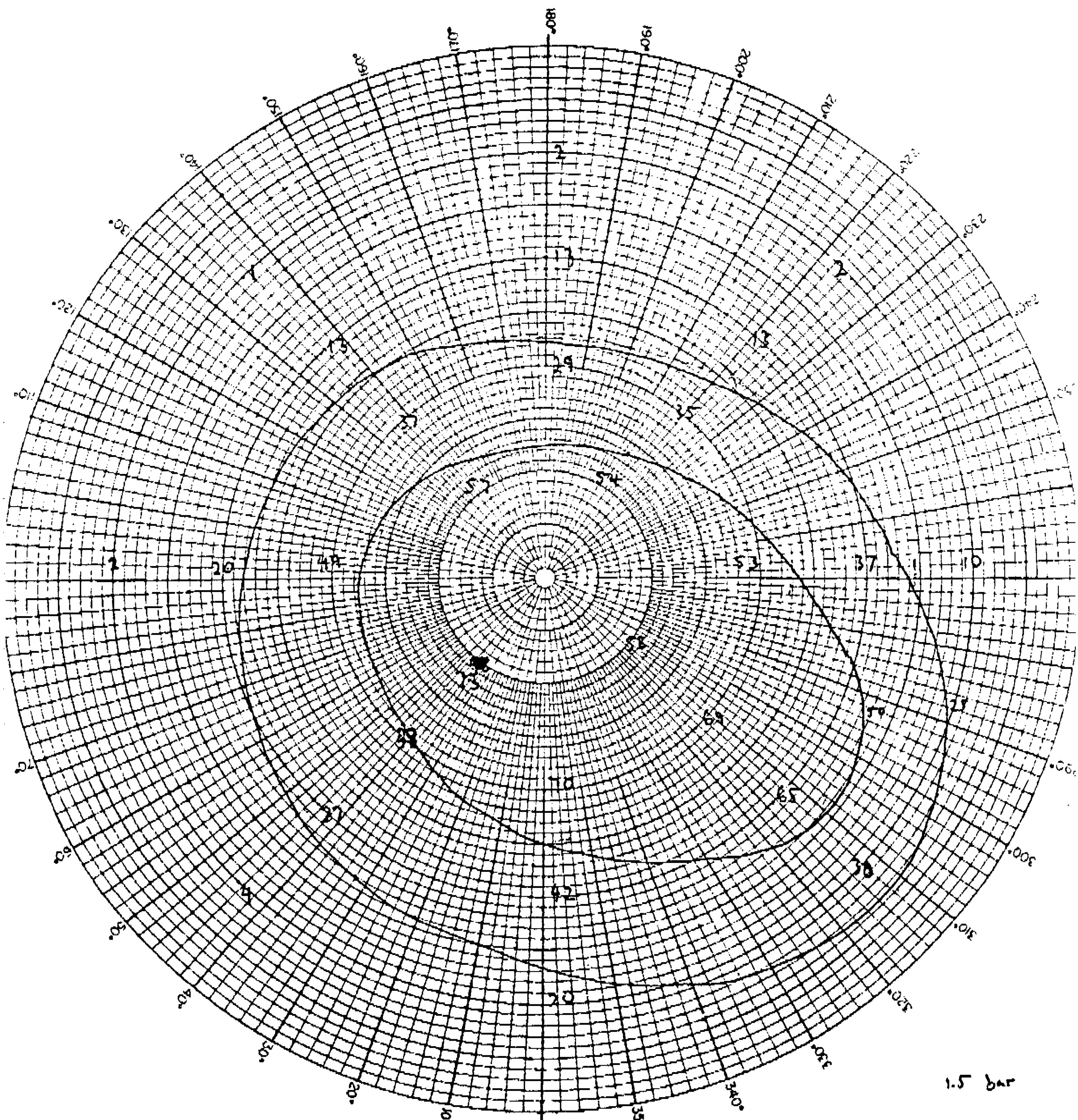
2 bar

x̄ = 65

3/4" NOZZLE 3m HEIGHT (mm depth / hr)

DU 2m 80%

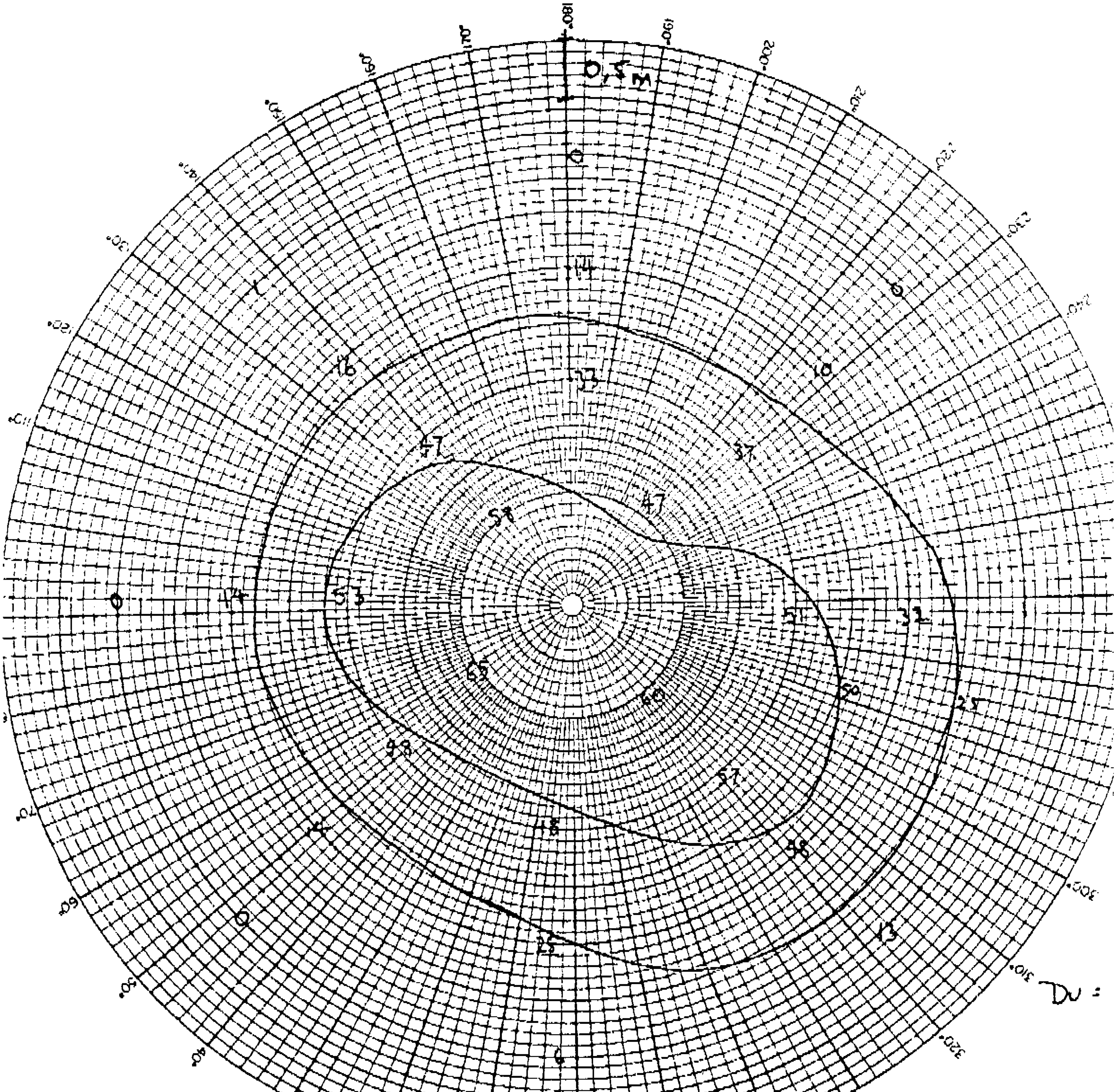
3m 62% 1.5 bar



(632)

3/4" NOZZLE 3m HEIGHT (mm depth/hr)

DU 2m 86 %
3m 60 % 1 bar



DU =

1 bar