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UNIVERSITY OF ALBERTA

NORMAN WELLS PIPELINE

RELATIONSHIPS BETWEEN SOIL PARAMETERS AND WHEEL DITCH PRODUCTION RATES IN PERMAFROST

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The University of Alberta

Relationships Between Soil Parameters and Wheel Ditch Production Rates in Permafrost

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend
to the Faculty of Graduate Studies and Research
for acceptance, a project report entitled
"Relationships Between Soil Parameters
and Wheel Ditch Production Rates in Permafrost",
submitted by Robert J. Saunders
in partial fulfillment of the requirements
for the degree of Master of Engineering.

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SUMMARY

The relationship between terrain and soil parameters and the ditch production rate using wheel ditchers in permafrost conditions is examined in this study. Correlations were developed based on the actual construction history of the Interprovincial Pipe Line from Norman Wells, N.W.T. to Zama, Alberta.

Several models were developed to predict ditch production rates in permafrost with different soil and terrain parameters. The simplest model is based on terrain analysis from air photo interpretation and the most complicated model involves moisture content and cobble frequency based on detailed borehole investigations. The strongest quantitative parameter affecting ditch production which was identified in this study was moisture content.

All models developed in the study to predict ditch production rate were compared to actual production rates achieved through the study area.

Comments on general factors influencing ditch production rate were also discussed.

ACKNOWLEDGEMENTS

The author wishes to thank Messrs. D. Wishart and A. Pick of Interprovincial Pipe Line Company for their cooperation and assistance in making all their files open for this study. Conversations with Mr. Alex Costin, of Hardy BBT Ltd., were also invaluable in piecing together some of the pipe line construction history.

Finally, the author wishes to thank Mr. Milos Stepanek of Geo-Engineering (M.S.T.) Ltd. for providing the time and support necessary to finish this study.

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1.0 INTRODUCTION

The Norman Wells to Zama pipeline is an oil pipeline which traverses approximately 868 km of discontinuous permafrost along the Mackenzie River valley. The pipeline is operated by Interprovincial Pipe Line Company (IPL) and carries oil from reserves at Norman Wells, N.W.T. owned by Esso Resources Canada Ltd. (Esso). The pipeline is rather unique in that it is the first major pipeline constructed in permafrost in Canada and one of the few in the world. Many design problems unique to permafrost and cold regions had to be considered throughout the entire project, with some being ongoing. Conditions of frost heave and thaw settlement which could produce large differential settlements or induce pipe stresses had to be allowed for.

Perhaps the most difficult obstacle to overcome was the actual construction of the pipeline. Little information was available to suggest the best means to excavate the pipeline trench or how much it would cost. There was no real precedence or experience other than ditching trials to compare past performance with the problems facing the pipeline designers.

This report summarizes the actual production achieved during construction and attempts to correlate ditch production rate with terrain type and soil parameters. In addition, some general comments on factors which affect overall production and logistics are also presented.

2.0 BACKGROUND

The Norman Wells to Zama pipeline is a 0.3 m diameter oil pipeline which follows the Mackenzie River valley through much of the Northwest Territories as shown in Figure 1. As the pipeline passes through very discontinuous permafrost where large frozen and unfrozen areas exist, the pipeline operating temperature was kept moderate and is considered passive as it is generally only a few degrees above freezing. Running a pipeline "chilled" or below freezing is advantageous in areas of continuous permafrost because thaw settlement is minimized. In very discontinuous permafrost, it is often more advantageous to operate the pipeline slightly above freezing to minimize the problems associated with ground freezing and frost heave.

The pipeline was constructed in the winters of 1983/84 and 1984/85. Winter construction was the only feasible time for construction as there are no all-weather roads to Norman Wells (only a winter road) due to the abundance of muskeg. Construction of the pipeline was undertaken in segments which were referred to as construction spreads. Initially, six spreads were proposed. During actual construction, these spreads overlapped somewhat and Spreads #2 and #3 were actually constructed together. Figure 2 is a flow chart highlighting the location of construction of spreads and the season they were constructed.

The majority of the pipeline was trenched using large wheel ditching machines specially designed for Arctic work. The machines were custom built twin engine 1200 HP excavators referred to as the Model 7-10 which corresponded to width and depth of ditch possible in feet. These machines were capable of excavating a smooth regular trench which made laying and backfilling much easier than in the backhoe excavated ditch. Typical burial depth for the pipeline in a normal right of way was between 1.1 and 1.2 m. Deeper burial was implemented at all road and stream crossings. Backhoes were employed in areas which could not support the weight of the ditching wheels and in areas of boulder tills where the ditching wheels could not physically excavate the soils.

Right of way disturbance was minimized as much as possible to preserve the natural peat. The presence of peat has an insulating effect which, in many cases, is the primary reason permafrost remains in discontinuous zones along much of the pipeline route. Ground temperatures are often near -1°C and the permafrost is classified as warm. Grading of the right of way was therefore kept to a minimum and generally restricted to snow removal. However, even with care, the organic mat was compressed significantly and likely to have diminished its insulating effect. This observation has no major implication to this study, but may be important when an evaluation of degradation of right of way due to thaw is evaluated after several years of pipeline operation.

During construction, daily progress at all stages of the project were recorded as well as very detailed field ditch logs which included soil and ice descriptions. These records, with the addition of alignment sheets and borehole information, formed the database for this study and are presented in the next section.

3.0 DATA SOURCES

As mentioned above, records kept in the field during construction, and a wealth of information collected for design were used in this study. The sources of data are listed below and will be discussed individually:

a) Daily Progress Reports (UMA - Canuck - Hardy)
b) Field Diaries of Ditch Inspectors (UMA - Canuck - Hardy)
c) Field Ditch Logs (UMA - Canuck - Hardy)
d) As-Built Alignment Sheets (IPL)
e) Borehole Databank (IPL - Hardy)
f) Geophysical Survey (Hardy)

3.1 DAILY PROGRESS REPORTS

Daily progress reports for a twenty-four hour period (end of dayshift to end of dayshift) were produced for each construction spread. The status of all work on the pipeline was monitored and the reports served as a project management tool to ensure the project kept on schedule. It was not designed to be a detailed record of ditch progress. However, the amount of kilometers trenched per day as well as general comments on trench progress, equipment downtime, air temperature, etc. were recorded on these reports. A typical progress report is presented in Figure 3.

The amount of trench excavated per day recorded was for all equipment working and did not distinguish between backhoe progress or wheel ditcher progress. In addition, the daily progress reports did not identify where on the route the trenching occurred. This information had to be inferred from the field ditch logs.

3.2 FIELD DIARIES

Field diaries were kept by most of the field inspectors. Typically, they contained comments on general progress during a shift, but often were not very specific. The field diaries were useful to obtain travel time for working out logistics and often had very good qualitative comments regarding ditch progress. However, as with most field diaries, they were not always filled with the same detail every day. No official record was required to be maintained on ditching rates and therefore it was not noted.

3.3 FIELD DITCH LOGS

Field ditch logs were prepared approximately at 100 m stations along the pipeline route. The pipeline trench was examined visually and detailed information on ice and soil conditions were recorded. As different inspectors with different technical abilities were assigned to various construction spreads, significant variations in soil description is apparent. In general, however, the logs are quite good and provide a good basis for determination of what kind of soil and terrain type was being ditched. The ditch logs were filled out daily and are therefore useful in determination of what area of trench was excavated on a given day. A typical ditch log is presented in Figure 4.

3.4 ALIGNMENT SHEETS

A complete set of "as-built" alignment sheets were provided by IPL on which working data for this study was plotted. The alignment sheets consist of photo mosaics covering the entire pipeline route which shows the actual pipeline alignment and "as-built" kilometer posts. Terrain units and their boundaries are plotted on the photo mosaics. The scale of the alignment sheets is 1:2000 which approximates to roughly 10 to 15 km per sheet.

The alignment sheets were used to code all terrain occurrences up to the Mackenzie River crossing. As the alignment sheets are prohibitively large, they are not included in this report.

3.5 BOREHOLE DATABANK

Over the past twenty years or so, many pipeline projects along the Mackenzie River Valley were proposed and several went to a fairly high level of design prior to their abandonment. Consequently, thousands of boreholes were drilled along a narrow transportation corridor which was set aside for future roads and pipelines. One of the proposed pipeline projects that got to a high level of design was the Beaufort-Delta Project. In the design process a database or databank of all boreholes drilled along this corridor was created and all borehole logs coded into a digital form. After abandonment IPL and Hardy Associates (1978) Ltd. revised the old Beaufort-Delta Project Databank and drew from it to estimate thaw settlement potential along the route. Hundreds of new boreholes drilled specifically for the Norman Wells-Zama pipeline were added to the databank.

This databank has been a key component to this study as it allows for quick access to geotechnical data which can be examined selectively along the route. In its current form the IPL Databank consists of approximately 3800 boreholes within 5 km of the pipeline from Norman Wells to Zama.

Each individual borehole was coded separately and stored as a single record in a computer file. The information stored in each record is explained below:

<u>Borehole Code:</u>	The borehole number and identifying series code.
<u>Terrain Type</u>:	An abbreviated terrain type which eliminates soil modifiers. (See Appendix "C").
<u>Kilometer Post</u>:	Slack chainage kilometer reference (Norman Wells KMP = 0).
<u>Depth Hole</u>:	Depth of borehole.
<u>Depth Peat</u>:	Depth of peat from the surface (0 if peat not encountered).
<u>Depth Bedrock</u>:	Depth to bedrock from ground surface. (100 if bedrock not encountered).
<u>Depth Permafrost</u>:	(See Figure 6).
<u>Depth Thaw</u>:	(See Figure 6).
<u>Depth Till</u>:	Depth to till from the surface. (100 if till not encountered).

<u>Cobbles</u>: 1 = cobbles present in borehole;
0 = no cobbles present.

<u>Limits</u>: 1 = Atterberg Limits for borehole;
0 = no Atterberg limits available.

<u>Grain Size</u>: 1 = Grain Size results available for borehole;
0 = no Grain Size results available.

<u>Strength</u>: 1 = Strength test, N-values from penetration tests, etc. available
0 = no strength data available.

<u>Depth</u>: Fixed for all boreholes.

Depth (Feet)	Layer
0 - 2	1
2 - 4	2
4 - 7	3
7 - 10	4
10 - 15	5
15 - 20	6
20 - 30	7
30 - 40	8

<u>Unified Classification</u>: Soil classification for each layer based on a weighted average (e.g. SM, CL, ML).

<u>Water Content</u>: Water content based on a weighted average for each layer. (Percent).

<u>Visible Ice</u>: The amount of visible or pure ice for each layer based on a weighted average. (Percent).

Bulk Density: Frozen bulk density based on a weighted average. (pcf).

A sample borehole from the databank is shown in Figure 5.

3.5.1 GEOTHERMAL CONDITION

Coding of thermal condition of the borehole log was achieved by the use of two variables referred to as depth of thaw (DT) and depth of permafrost (DP). Various permafrost conditions were able to be represented as shown in Figure 6. Seasonal frost was defined as any frozen material at the surface less than 5 feet in thickness and was ignored in the databank.

3.5.2 IDENTIFICATION OF TILL

The presence of till was another important variable identified in the databank. All soil was classified by the United Soil Classification System (USC) and the term "till" reflects the origin of a soil, not its classification by USC. However, soils of a till origin in the Mackenzie Valley perform much differently than lacustrine soils and hence a need existed to classify tills separately from other fine grained soils. Tills along the Mackenzie Valley tend to be fine grained silts and clays with occurrences of cobbles and boulders. Till is identified in the databank as a depth to till. (Figure 7). The underlying assumption here is of course, that till is generally the lower stratum and the likelihood of a till deposit overlying a lacustrine deposit is low along the pipeline route.

In order to assess how accurate the coding of till was in the databank, an examination of till occurrences against terrain type was undertaken. Figures 8 and 9 show the percentage of boreholes with and without till plotted for each terrain type. As can be seen, 83 percent of the holes classified as MG (glacial moraine) were logged as till. As well, 81 percent of the LP (lacustrine) deposits had no till. In the remaining 19 percent of the LP group that had till, the average depth to till was 2.6 metres, well below the average depth of pipeline burial, and below the normal depth to which terrain analysis by aerial photo mapping is accurate.

Based on the above findings, the use of the till variable as coded in the databank was used to override the USC classification and was used to identify tills for this study. Bedrock was identified in a similar fashion as shown in Figure 10 but its occurrence along the pipeline route was minor, and not considered in any great detail.

3.5.3 VISIBLE ICE/MOISTURE CONTENT

Information regarding visible ice and moisture content were stored for each soil layer as well. In order to assess the usefulness of the visible ice parameter initially, a correlation for each USC was attempted for all frozen boreholes with both ice and moisture content data. The results are presented in Appendix "B".

The conclusion after a review of the data above, was that only rough correlations between ice and moisture content existed and the usefulness of the visible ice parameter was considered minor. This discovery likely reflects the variability of moisture content within permafrost in general, and that segregation and migration of water to freezing fronts is ongoing. Sampling techniques for moisture content either smooth or exaggerate these differences.

After reviewing the data in the IPL Databank, it appeared the databank was sufficiently accurate and detailed to be used in this study. Software was developed to manipulate data and select specific information at any point along the pipeline route. This information was used in conjunction with the other data to derive correlations of soil parameters and terrain type with ditch production.

3.6 CONTINUOUS GEOPHYSICS

As part of the investigation to delineate soil and permafrost conditions along the pipeline route, continuous geophysics was undertaken by Hardy Associates (1978) Ltd. between March 1981 and May 1982. The survey was undertaken with the EM-31 and EM-34. Both instruments measure apparent conductivity of the subsurface conditions. The shallowest possible survey with the above equipment was with the EM-31 on its side, which measured conductivity in the top 3.5 m. The deepest measurements were with the EM-34 which had a range up to 9.0 m.

Apparent conductivity is very difficult to use to positively identify soil or permafrost conditions even in a homogeneous soil without layering. Quantitatively, there is considerable overlap in apparent conductivities between one soil to another as well as with different geothermal conditions as shown in Figure 11.

The geophysical survey undertaken by Hardy Associates (1978) Ltd. was therefore interpreted with the assistance of vegetative indicators and detailed boreholes drilled on the centre line of the right of way. Figure 12 shows how sharp frozen and unfrozen boundaries can be identified in a uniform soil. As well, Figure 13 shows how soil changes can be identified for an area of constant geothermal conditions.

In reviewing the geophysical data, however, it became obvious that it was not a predictive tool which could be used on its own and apparent conductivity was a variable which could not be correlated quantitatively to production rate. Geophysical signatures are more correctly interpreted by shape or trends rather than absolute values which would be impractical to use in this study. As well, our depth of interest is approximately 1.2 m and the shallowest geophysics available considers the top 3.5 m.

As a result, the geophysical data was not considered in the correlations with ditchability and was only used to assess permafrost distribution along the pipeline route.

4.0 STUDY AREA SELECTION

The selection of the study area was based on the availability of data and predominance of permafrost. The intent of this study was to concentrate on ditchability of permafrost conditions. It therefore needed to be limited to areas with greater than 50 percent of the route in permafrost. The distribution of permafrost was examined first by looking at permafrost distribution by geophysics along the pipeline route and then by distribution of frozen boreholes in the borehole databank. The results are discussed in the following section.

4.1 PERMAFROST DISTRIBUTION

The distribution of permafrost as determined by geophysics is shown plotted in Figure 14 for approximately 50 km intervals along the pipeline route. As can be seen, there is an obvious decrease in permafrost as one moves south along the pipeline route. The average permafrost distribution is around 70 percent for the first 500 km and then drops off quickly to around 30 to 40 percent for the rest of the route.

Another means of determining permafrost distribution along the pipeline route was by frequency of frozen boreholes within the borehole databank. This is somewhat of a more crude indicator of permafrost distribution along the pipeline route as boreholes are often clustered in small local areas and are not truly random. Figure 15 shows the permafrost distribution by boreholes for 50 km intervals. As can be seen, the permafrost decreases as one moves south along the pipeline route and more partially frozen holes are encountered. The results are very similar to those obtained from the geophysical survey.

Based on these two distributions, it appeared that permafrost becomes rather discontinuous south of kilometer post 500. This also corresponded to construction spreads 1 to 4.

4.2 BOREHOLE DISTRIBUTION

As mentioned earlier, the borehole databank is a compilation of many previous drilling programs as well as all boreholes drilled for the Norman Wells to Zama pipeline. There are approximately 3800 boreholes within the IPL databank within a 5 km corridor of the pipeline alignment. The frequency of boreholes for 10 km intervals along the pipeline route is shown in Figure 16. This serves as a reasonable indication of the quality of the databank by kilometer post and is a good indicator where the geotechnical data coverage is highest.

As can be seen, borehole information becomes limited south of approximately kilometer post 550 and boreholes become spaced on average less than 1 per kilometer.

4.3 CONSTRUCTION SPREADS

As mentioned earlier, the pipeline route was constructed in what were referred to as construction spreads. Construction spreads 1 to 4 were from kilometer post 0 to 528. This geographically corresponds to all of the pipeline route north and east of the Mackenzie River.

As there appeared to be little borehole data south of the Mackenzie River crossing and permafrost was becoming more discontinuous, the study area seemed to define itself quite conveniently, as all of the pipeline route north and east of the Mackenzie River or kilometer post range 0 to 528.

5.0 TERRAIN TYPE CLASSIFICATION AND DISTRIBUTION

An important component of all the design criteria established for the pipeline route was the classification of terrain types. Terrain types or units are basically areas which are composed of similar soils deposited in a similar fashion. The science of Terrain Analysis is highly dependent on the use of aerial photographs (generally viewed in stereo) to determine areas of similar geomorphology and soil type. The terrain typing system used for the IPL project is presented in Appendix C. For the purposes of simplification, the terrain types were originally condensed and soil modifiers dropped and a two character terrain type was developed, which all the boreholes in the borehole databank were assigned. This simplified terrain classification system is summarized in Appendix C.

In order to evaluate the occurrences of terrain types found along the pipeline route, the as-built length of each terrain unit was measured from the alignment sheets and entered into a computer file. By accessing this computer file, statistical information regarding percentage of occurrence of each terrain type was possible for any given kilometer post range.

A summary breakdown of terrain occurrence for the total study area (KMP 0-528) is shown in Figure 17. As can be seen, approximately five terrain units dominate the study area. In general, the route consists of till moraines and lacustrine blankets with varying organic cover.

6.0 COMPILATION OF PRODUCTION AND LOGISTICS DATA

The most difficult variable to accurately quantify for this study was unfortunately the most important one and that is the actual ditching rate for a given area. The overall or gross production rate is well documented, but factors like percentage of ditch excavated by backhoe, mechanical downtime and travel time were not documented in detail and have had to be estimated, based on memory of the ditch inspectors, diaries and comments on progress reports.

The factors which were considered in estimating the actual production rate are discussed in the following sections. Table 1 summarizes the ditching progress and logistics on approximately a daily basis for all construction spreads.

6.1 TRAVEL TIME/CAMP LOCATION

In the winter of 1983/84, only one camp existed for each of Construction Spread #1 and #4. Towards the ends of the spreads, travel time was playing a heavy role on overall production as it was taking up to three hours for each shift to reach the site from camp. Based on records in diaries, it appeared travel time was fairly consistent along the route and an average of 0.023 hours/kilometer were being lost per shift due to travel time.

This logistics problem was identified by the contractors and IPL and in the following winter of 1984/85, small intermediate camps were established for the ditching crew to minimize travel time.

Based on these observations, it was a simple task to estimate how much of each shift was lost on travel for the entire study area. Figure 18 shows the number of hours per shift lost for locations along the pipeline route.

6.2 BACKHOE DITCH

The percentage of backhoe ditch was not recorded accurately in Construction Spreads #1, #2 and #3. However, discussions with Mr. Alex Costin of Hardy BBT Ltd. confirmed an estimate of 15 to 20 percent of these zones to be excavated by backhoe. Construction

TABLE 1 SPREADSHEETS

CONSTRUCTION SPREAD #1 KP 0.00 - 190.051

DATE	TOTAL km	%DITCH	DITCH km	NO. OF DITCHERS	DOWN %	TRAVEL/ SHIFT(hr)	PROD. HOURS	PROD. m/hr	TERRAIN TYPE	USC	MC	%COBBLES	KILOMETER POST
JAN 25/84	0.4	80	0.32	2	20	1.9	35.4	9.0	14	M	-1	100	0.22
JAN 26/84	1.4	80	1.12	2	20	1.9	35.4	31.7	14	M	-1	20	1.1
JAN 27/84	0.4	80	0.32	2	20	1.9	35.4	9.0	27	M	-1	0	2.28
JAN 28/84	1.3	80	1.04	2	30	1.9	30.9	33.6	15	T	12	85	3.11
JAN 29/84	1.2	80	0.96	2	30	1.9	30.9	31.0	15	T	12	100	3.99
JAN 30/84	2.1	80	1.68	2	30	1.8	31.1	54.1	14	T	12	90	5.46
JAN 31/84	1.9	80	1.52	2	20	1.8	35.5	42.8	14	T	12	95	7.5
FEB 1/84	3.7	80	2.96	2	30	1.7	31.2	94.8	14	M	60	75	10.65
FEB 2/84	0.8	80	0.64	1	80	1.6	9.3	69.0	14	G	11	100	12.9
FEB 3/84	2.1	80	1.68	1	75	1.6	11.6	144.8	19	T	-1	80	14.75
FEB 4/84	1.5	80	1.20	2	40	1.5	27.0	44.4	15	T	-1	100	-1
FEB 5/84	2.7	80	2.16	2	20	1.5	36.0	60.0	35	G	14	60	20.36
FEB 6/84	3.0	80	2.40	2	50	1.4	22.6	106.2	33	G	-1	50	21.96
FEB 7/84	1.7	80	1.36	2	60	1.4	18.1	75.2	33	T	-1	-1	-1
FEB 8/84	1.7	80	1.36	2	40	1.3	27.2	49.9	36	X	-1	-1	-1
FEB 9/84	2.7	80	2.16	2	30	1.3	31.8	68.0	36	X	-1	-1	-1
FEB 10/84	1.9	80	1.52	2	40	1.2	27.4	55.6	36	X	-1	-1	-1
FEB 11/84	2.1	80	1.68	2	20	1.1	36.6	45.9	33	X	-1	90	37.95
FEB 12/84	4.4	80	3.52	2	20	1.1	36.6	96.1	19	T	21	85	33.85
FEB 13/84	5.0	80	4.00	2	20	0.9	37.0	108.2	19	M	78	25	40.85
FEB 14/84	9.0	80	7.20	2	10	0.8	41.8	172.4	19	M	74	10	47.7
FEB 15/84	4.1	80	3.28	2	10	0.6	42.1	77.9	19	T	46	80	54.6
FEB 16/84	4.5	80	3.60	2	20	0.5	37.6	95.7	19	T	46	70	57.45
FEB 17/84	5.4	80	4.32	2	40	0.4	28.3	152.5	35	T	34	75	61.35
FEB 18/84	2.4	80	1.92	2	90	0.2	4.8	403.4	35	T	-1	75	69.15
FEB 19/84	2.9	80	2.32	2	50	0.2	23.8	97.5	19	T	39	90	71.05
FEB 20/84	1.5	80	1.20	2	40	0.1	28.7	41.8	19	T	39	95	73
FEB 21/84	4.5	80	3.60	2	50	0.1	23.9	150.6	19	M	38	70	75.9
FEB 22/84	1.5	80	1.20	2	40	0	28.8	41.7	32	S	30	25	78.85
FEB 23/84	4.5	80	3.60	2	40	0.1	28.7	125.5	32	S	31	5	80.75
FEB 24/84	4.6	80	3.68	2	40	0.2	28.6	128.9	14	M	30	0	86.55
FEB 25/84	6.0	80	4.80	2	40	0.3	28.4	168.8	14	S	43	0	89.52
FEB 26/84	7.5	80	6.00	2	20	0.5	37.6	159.6	14	M	36	0	100.25
FEB 27/84	5.8	80	4.64	2	20	0.7	37.3	124.5	32	S	36	0	102.3
FEB 28/84	5.4	80	4.32	2	20	0.8	37.1	116.4	32	S	16	0	111.25
FEB 29/84	5.8	80	4.64	2	20	0.9	37.0	125.5	32	S	16	0	115.1
MAR 1/84	8.2	80	6.56	2	20	1.1	36.6	179.0	11	S	15	0	123.1
MAR 2/84	5.1	80	4.08	2	75	1.3	11.4	359.5	27	S	-1	0	128.85
MAR 3/84	4.7	80	3.76	2	65	1.4	15.8	237.7	27	S	21	0	133.35
MAR 4/84	3.9	80	3.12	2	20	1.5	36.0	86.7	27	S	27	0	138.05
MAR 5/84	3.5	80	2.80	2	50	1.6	22.4	125.0	14	S	12	30	141.85
MAR 6/84	4.3	80	3.44	2	20	1.7	35.7	96.4	14	T	21	100	145.75
MAR 7/84	1.3	80	1.04	1	75	1.7	11.6	89.8	36	X	-1	0	-1
MAR 8/84	5.2	80	4.16	1	65	1.8	16.2	257.3	14	T	35	95	150.7
MAR 9/84	6.0	80	4.80	1	65	2	16.1	298.1	14	G	15	30	157.57
MAR 10/84	2.3	80	1.84	1	60	2	18.4	100.0	36	M	80	-1	-1
MAR 11/84	4.2	80	3.36	1	65	2.1	16.1	209.2	15	M	80	85	163.47
MAR 12/84	3.4	80	2.72	1	65	2.2	16.0	169.7	15	M	80	40	168.45
MAR 13/84	3.0	80	2.40	1	65	2.3	16.0	150.0	15	C	34	50	171.5
MAR 14/84	2.5	80	2.00	2	50	2.4	21.6	92.6	15	M	32	100	174.55
MAR 15/84	1.6	80	1.28	2	30	2.5	30.1	42.5	15	C	32	80	176.55
MAR 16/84	4.2	80	3.36	2	20	2.5	34.4	97.7	15	T	27	60	179.55
MAR 17/84	5.2	80	4.16	2	30	2.7	29.8	139.5	14	M	32	60	183.55
MAR 18/84	4.1	80	3.28	2	50	2.8	21.2	154.7	14	M	32	0	188.67

TABLE 1 (cont'd) SPREADSHEETS

CONSTRUCTION SPREAD #2 KP 190.05 - 263.45

DATE	TOTAL km	%DITCH	DITCH km	NO. OF DITCHERS	DOWN %	TRAVEL/ SHIFT(hr)	PROD. HOURS	PROD. m/hr	TERRAIN TYPE	USC	MC	%COBBLES	KILOMETER POST
JAN 14/85	2.3	80	1.84	2	45	0.9	25.4	72.4	15	M	25	0	191.67
JAN 15/85	2.4	80	1.92	2	20	0.8	37.1	51.7	14	M	25	40	194.3
JAN 16/85	2.5	80	2.00	2	20	0.7	37.3	53.6	14	T	31	60	196.3
JAN 17/85	1.8	80	1.44	2	20	0.7	37.3	38.6	12	T	20	90	200.3
JAN 18/85	3	80	2.40	2	20	0.6	37.4	64.1	32	T	10	80	202.3
JAN 19/85	6.5	80	5.20	2	20	0.5	37.6	138.3	12	G	30	0	207.3
JAN 20/85	6.2	80	4.96	2	20	0.3	37.9	130.8	30	G	7	0	216.3
JAN 21/85	4.7	80	3.76	2	20	0.2	38.1	98.7	12	C	30	0	219.25
JAN 22/85	5.1	80	4.08	2	60	0	19.2	212.5	12	I	-1	10	224.25
JAN 23/85	0	80	0.00	2	100	0	0.0	0.0	5	I	-1	-1	-1
JAN 24/85	0	80	0.00	2	100	0	0.0	0.0	5	I	-1	-1	-1
JAN 25/85	0	80	0.00	2	100	0	0.0	0.0	5	I	-1	-1	-1
JAN 26/85	0.4	80	0.32	2	100	0	0.0	0.0	5	I	-1	-1	-1
JAN 27/85	0.4	80	0.32	2	90	0	4.8	66.7	5	C	-1	-1	-1
JAN 28/85	3.7	80	2.96	2	20	0.1	38.2	77.4	5	C	31	95	228.3
JAN 29/85	2.5	80	2.00	2	20	0.1	38.2	52.3	5	C	34	90	232.3
JAN 30/85	3.3	80	2.64	2	20	0.2	38.1	69.3	36	C	37	90	236.3
JAN 31/85	3.1	80	2.48	2	20	0.3	37.9	65.4	14	C	37	95	238.3
FEB 1/85	6	80	4.80	2	20	0.4	37.8	127.1	14	C	35	0	242.3
FEB 2/85	5.9	80	4.72	2	20	0.6	37.4	126.1	14	C	52	0	248.3
FEB 3/85	5.5	80	4.40	2	20	0.5	37.6	117.0	14	C	69	0	254.3
FEB 4/85	6.1	80	4.88	2	20	0.6	37.4	130.3	15	C	55	0	260.4
FEB 5/85	2	80	1.60	2	20	0.5	37.6	42.6	15	C	41	0	-1

CONSTRUCTION SPREAD #3 KP 263.45 - 338.30

DATE	TOTAL km	%DITCH	DITCH km	NO. OF DITCHERS	DOWN %	TRAVEL/ SHIFT(hr)	PROD. HOURS	PROD. m/hr	TERRAIN TYPE	USC	MC	%COBBLES	KILOMETER POST
FEB 5/85	4.7	80	3.76	2	20	0.5	37.6	100.0	14	C	41	0	265.52
FEB 6/85	7.1	80	5.68	2	20	0.3	37.9	149.8	14	C	35	0	271.5
FEB 7/85	4	80	3.20	2	20	0.2	38.1	84.0	14	C	35	5	277.5
FEB 8/85	4.3	80	3.44	2	20	0.1	38.2	90.0	14	C	20	15	281.5
FEB 9/85	5.2	80	4.16	2	20	0	38.4	108.3	32	C	5	10	286.5
FEB 10/85	4.8	80	3.84	2	20	0.2	38.1	100.8	14	C	10	0	291.5
FEB 11/85	5	80	4.00	2	20	0.3	37.9	105.5	14	C	15	0	296.5
FEB 12/85	6	80	4.80	2	20	0.4	37.8	127.1	1	G	2	20	305.5
FEB 13/85	5.5	80	4.40	2	20	0.6	37.4	117.5	14	S	13	30	309.5
FEB 14/85	5.2	80	4.16	2	20	0.7	37.3	111.6	14	C	35	0	314.5
FEB 15/85	5	80	4.00	2	20	0.9	37.0	108.2	14	C	37	0	319.5
FEB 16/85	4.8	80	3.84	2	20	1	36.8	104.3	32	C	39	0	323.5
FEB 17/85	4.7	80	3.76	2	20	1.1	36.6	102.6	32	S	16	5	328.5
FEB 18/85	4.6	80	3.68	2	20	1.2	36.5	100.9	30	S	14	10	333.5
FEB 19/85	3.8	80	3.04	2	20	1.2	36.5	83.3	36	S	11	-1	336.82

TABLE 1 (cont'd) SPREADSHEETS

CONSTRUCTION SPREAD 04 KP 338.30 - 528.30

DATE	TOTAL km	%DITCH	DITCH km	NO. OF DITCHERS	DOWN %	TRAVEL/ SHIFT(hr)	PROD. HOURS	PROD. m/hr	TERRAIN TYPE	USC	MC	%COBBLES	KILOMETER POST
JAN 24/84	0.3	10	0.03	2	100	2	0.0	0.0	19	X	-1	90	527.95
JAN 25/84	0.5	10	0.05	2	100	2	0.0	0.0	19	X	-1	75	527.35
JAN 26/84	0	10	0.00	2	100	2	0.0	0.0	19	X	-1	100	526.93
JAN 27/84	0.5	10	0.05	2	90	2	4.4	11.4	19	X	-1	100	526.5
JAN 28/84	0	10	0.00	2	60	2	17.6	0.0	19	X	-1	80	525.44
JAN 29/84	1.2	10	0.12	2	60	1.9	17.7	6.8	19	X	-1	15	524.36
JAN 30/84	3.6	10	0.36	2	60	1.7	17.8	20.2	19	X	-1	30	522.31
JAN 31/84	5.2	10	0.52	2	60	1.8	17.8	29.3	22	X	-1	10	519.8
FEB 1/84	3	10	0.30	2	60	1.6	17.9	16.7	33	X	-1	50	551
FEB 2/84	5	10	0.50	2	20	1.5	36.0	13.9	33	X	-1	10	511.35
FEB 3/84	3.5	10	0.35	2	20	1.5	36.0	9.7	33	X	-1	0	505.8
FEB 4/84	3.3	10	0.33	2	20	1.4	36.2	9.1	32	X	-1	95	503.42
FEB 5/84	1.4	10	0.14	2	20	1.4	36.2	3.9	12	X	-1	100	500.9
FEB 6/84	1.4	10	0.14	2	20	1.3	36.3	3.9	12	X	-1	100	499.7
FEB 7/84	3.6	10	0.36	2	20	1.3	36.3	9.9	32	X	-1	20	497.25
FEB 8/84	5.3	10	0.53	2	20	1.1	36.6	14.5	32	X	-1	10	492.67
FEB 9/84	6.6	10	0.66	2	20	1	36.8	17.9	15	X	-1	0	486.97
FEB 10/84	6.7	10	0.67	2	20	0.9	37.0	18.1	10	X	-1	20	481.27
FEB 11/84	4.9	30	1.47	2	20	0.7	37.3	39.4	14	X	-1	0	475.57
FEB 12/84	3.9	10	0.39	2	20	0.6	37.4	10.4	14	X	-1	0	470.5
FEB 13/84	2	10	0.20	2	20	0.5	37.6	5.3	22	X	-1	10	467.6
FEB 14/84	3.8	50	1.90	2	20	0.4	37.8	50.3	32	X	-1	30	464.65
FEB 15/84	2.4	10	0.24	2	40	0.4	28.3	8.5	32	X	-1	20	461.65
FEB 16/84	2.7	10	0.27	2	75	0.3	11.8	22.8	32	X	-1	30	458.65
FEB 17/84	3.8	15	0.57	2	20	0.2	38.1	15.0	15	X	-1	20	455
FEB 18/84	4	30	1.20	2	40	0.1	28.7	41.8	32	X	-1	5	451.4
FEB 19/84	6	20	1.20	2	20	0	38.4	31.3	19	X	-1	5	446.45
FEB 20/84	3.8	5	0.19	2	20	0.1	38.2	5.0	19	X	-1	10	441.45
FEB 21/84	4.6	5	0.23	2	20	0.2	38.1	6.0	19	X	-1	15	437.45
FEB 22/84	6.1	30	1.83	2	20	0.4	37.8	48.5	19	X	-1	15	431.95
FEB 23/84	6.5	40	2.60	2	20	0.5	37.6	69.1	19	X	-1	5	425.25
FEB 24/84	6.5	15	0.97	2	20	0.7	37.3	26.2	33	X	-1	10	418.7
FEB 25/84	7.2	60	4.32	2	20	0.9	37.0	116.9	19	X	-1	0	412.55
FEB 26/84	6.2	40	2.48	2	20	1	36.8	67.4	19	X	-1	20	412.35
FEB 27/84	6.8	40	2.72	2	20	1.2	36.5	74.6	19	X	-1	0	399.27
FEB 28/84	6.5	80	5.20	2	20	1.4	36.2	143.8	19	X	-1	10	392.8
FEB 29/84	7.9	95	7.50	2	20	1.6	35.8	209.4	13	X	-1	5	388.8
MAR 1/84	2.9	0	0.00	2	100	1.7	0.0	0.0	19	X	-1	40	379.15
MAR 2/84	2.6	0	0.00	2	20	1.7	35.7	0.0	19	X	-1	90	377.22
MAR 3/84	6.5	20	1.30	2	20	1.9	35.4	36.8	19	X	-1	25	372.9
MAR 4/84	5.4	15	0.81	2	20	2	35.2	23.0	19	X	-1	40	366.82
MAR 5/84	8.7	65	5.65	2	20	2.2	34.9	162.1	19	X	-1	15	359.85
MAR 6/84	4.6	25	1.15	2	20	2.4	34.6	33.3	19	X	-1	20	352.85
MAR 7/84	4.4	10	0.44	2	20	2.5	34.4	12.8	19	X	-1	25	348.7
MAR 8/84	5.5	80	4.40	2	20	2.6	34.2	128.5	19	X	-1	5	344.15
MAR 9/84	2.7	80	2.16	2	20	2.7	34.1	63.4	30	X	-1	10	339.77

Spread #4 was dramatically different in that the wheel ditchers struggled in extremely bouldery material. At times, seven 245 Caterpillar backhoes were working in conjunction with the wheel ditchers. Fortunately, the ditch inspectors generally noted on the ditch logs what areas were backhoe ditch and what areas were wheel ditch. In Spread #4, backhoe ditch varied from 10 to 90 percent of the daily production.

6.3 DOWNTIME

Generally two wheel ditchers were working in Construction Spreads #1, #2, #3, and #4 most of the time on twenty-four hour shifts. Due to the cold working conditions, even a "good" day would likely have 20 percent downtime for replacement of teeth and shanks. Longer periods of downtime were estimated from comments regarding major or minor repairs. Major repairs generally constituted half to a full shift. If a wheel ditcher was down any longer than this, it was generally noted on the daily progress reports.

Once all the production data and logistics had been established on a daily basis, spreadsheets were developed for each construction spread and are presented in Table 1. The overall trench production was adjusted for downtime, percentage backhoe ditch, etc. until the final actual production rate expressed in metres/hour averaged for the day was calculated.

The next step was to assemble all the soils and terrain information and attempt to correlate production rate with soil parameters. This is discussed in the following sections.

7.0 COMPILATION OF SOILS AND TERRAIN DATA

Once the production rates had been established on a daily basis, average soil conditions encountered during that day had to be determined. Soil type was determined from the ditch logs which often was not as detailed as a Unified Soil Classification (USC) but would classify soils as silt, clay, sand, gravel, or till. Through zones of variable soil and varying terrain types, the dominant soil type was selected as representative for purposes of this study.

The terrain type was established as the dominant terrain unit encountered on a daily basis from the location of the trench with respect to original terrain typing on the alignment sheets. Through areas of variable terrain type, the dominant terrain unit was selected and tabulated with the other soil parameters.

Cobbles were identified on ditch logs as to whether they were frequent enough to meet the requirement for sand or fluffed bedding. This criterion was any area with the occurrence of two or more cobbles greater than 150 mm in diameter within 10 m of each other. The percentage of ditch trench requiring bedding during a day was calculated and tabulated.

Permafrost was much more difficult to assess in that even the unfrozen zones were reported to have a significant depth of seasonal frost. The depth of frost was not accurately recorded at all locations and unfortunately an accurate assessment of the amount of frozen ground was not possible. It is assumed for this study that most trench was frozen to at least 50 percent. Qualitatively, it would appear the area near the Mackenzie crossing had less permafrost, yet had the greatest degree of difficulty to construct.

All the soil parameters and terrain types are summarized with production rates in Table 1 for each construction spread.

8.0 CORRELATION OF PRODUCTION WITH SOIL AND TERRAIN PARAMETERS

Once all data was tabulated, it was a straightforward task to plot one soil parameter at a time against actual production rate. Certain data was discarded upon closer inspection as it was clearly non-representative and estimates of downtime were likely in error.

The five soil parameters which were available to correlate production rate with were as follows:

1) terrain type
2) soil type
3) moisture content
4) cobble frequency (based on bedding criteria)
5) permafrost frequency (based on geophysics).

8.1 TERRAIN TYPE

During construction, a common observation by most personnel involved in the pipeline construction, was that glacial tills were much more difficult to ditch than other terrain types. The common feeling was that tills had a higher frequency of cobbles and boulders and this was felt to be the primary reason for slower production rates.

An average production rate was calculated for each different terrain unit within the study area, and the results are shown in Figure 19. Many of the terrain units are very minor in occurrence and it is likely the calculated production rate is not truly representative. However, the five dominant terrain types (which represent 75 percent of the route) have more data and are likely more realistic. These five dominant terrain units are shown in Figure 20 plotted with average production rates. The results are also shown in Table 2.

As can be seen, glacial tills (terrain typed as MG) are approximately twice as difficult to ditch than the lacustrine deposits (terrain typed as LP). The terrain type LP-MG (which represents a lacustrine veneer over till) has a production rate between the tills and lacustrine deposits which appears highly reasonable.

TABLE 2 - PRODUCTION RATE BASED ON TERRAIN TYPE

Terrain Type	Production Data (m/hr.)
LP	107
LP-MG	85
MG	60
OV-LP	67
OV-MG	41

8.2 SOIL TYPE

The soil types as obtained from the ditch logs were correlated with production rate and are shown plotted in Figure 21. A similar finding to the terrain type correlation is apparent in that till soils are more difficult to ditch than lacustrine or alluvial deposits. The results are summarized in Table 3.

TABLE 3 - PRODUCTION RATE BASED ON SOIL TYPE

Soil Type	Production Data (m/hr.)
Clay	103
Silt	129
Sand	122
Gravel	104
Till	75

8.3 MOISTURE CONTENT

As moisture content is generally a good indicator of soil behavior, it was considered an important variable to attempt to correlate with ditchability. Moisture content data was separated for soil types of sand and gravel, silt, clay, and till. Peat and organic silt were not included as areas where they extend to full depth of the ditch trench were local and did not represent a large percentage of the study area. In addition, moisture contents in these materials are extremely variable.

Moisture contents were plotted for the four identified soil types against production rate as shown in Figure Nos. 22 to 25. As can be seen, there appears to be a rough relationship between ditchability and moisture content. Linear regression was performed on each soil type with sufficient data, allowing production rate to be the dependent variable and moisture content, the independent variable. This produced a correlation as shown in each of the figures as Line A. Due to the scatter in the data, this produced a correlation which did not visually fit the data very well and suggested that only a weak correlation existed.

To improve upon the visual fit, another regression analysis was performed assuming moisture content was the dependent variable and production rate was the independent variable. This regression analysis is shown plotted on the figures as Line B. A better fit to the data in cases such as this, where the data is prone to large errors, is somewhere between the two regression lines[4]. This technique was used to improve thaw settlement correlations with moisture contents in the paper by Hanna et al[3].

No attempt was made at this time to remove any influence of other variables such as cobbles or permafrost distribution.

An interesting observation which came out of this exercise was that the correlations for clay and till were nearly identical, yet the data sets were shifted in different positions on the graph. The correlation for silt appeared very similar as well. The correlation for sand was different and was not considered in the same class. An additional correlation was then developed for fine-grained material which consisted of clays, silts and tills and is presented in Figure 26. All moisture content correlations are summarized in Table 4.

TABLE 4 - PRODUCTION RATE BASED ON MOISTURE CONTENT

Soil Type	Production Rate Correlation (m/hr.)
Sand	PR = 3.90 (MC%) + 40.0
Silt	PR = 2.29 (MC%) + 15.0
Clay	PR = 3.00 (MC%)
Till	PR = 2.83 (MC%)
Fine Grained (Clay, silt, till)	PR = 2.67 (MC%) + 15.0

This was a very interesting observation which suggested that tills are certainly on average more difficult to ditch than silts and clays, but it may be more closely related to the much lower average moisture content than to texture or cobble frequency. Tills generally do have cobbles and this variable is discussed in the next section. However, the question arises as to how many cobbles will actually slow down the ditching wheel. It seems reasonable in many less stony tills that the correlation with moisture content would be more dominant.

8.4 COBBLE FREQUENCY

The great difficulty in attempting to correlate production rate with cobble frequency is in the way we measure cobble frequency. The percentages of trench which required bedding was based on a criteria defined in the Construction Bid Document as follows:

> "Clause 7.4.1.10 to apply when two or more 150 mm dia. plus cobbles present in 10 m of ditch and to remain in effect until no such cobbles present for 50 m of ditch."

From a bedding perspective, where the intent is to minimize point loads on the pipeline, this may be considered a lot of cobbles. However, from a ditching wheel perspective, it seems unlikely two cobbles within 10 m of each other would significantly affect production rate. In areas where numerous cobbles (or boulders) are present, there is no question it seems difficult or impossible to excavate by wheel ditchers. Our problem arises in how do we identify these areas.

The other source of data which has some information on cobble frequency is the borehole databank. However, a small diameter drill hole can often penetrate through a bouldery till unless the deposit is maybe 25 percent cobbles. The point being, a drill hole samples too small an area and boreholes are spaced too great for an accurate determination of cobble frequency to be made based on boreholes alone.

After having stated the problems with quantifying cobble frequency, our data was still plotted for each of the four soil groups and collectively as shown in Figure Nos. 27 to 31. On observation, there appears to be a trend that increasing cobble frequency decreases production in the clays and tills. Correlation for each of the soil groups was therefore developed in a similar fashion for cobble frequency as was done for moisture content, and are summarized in Table 5. The best fit for all the data was visually determined to be "Line A" and was used in the predictive models.

TABLE 5 - PRODUCTION RATE BASED ON COBBLE FREQUENCY

Soil Type	Production Rate Correlation (m/hr.)
Sand	PR = 4.01 (CF%) + 35.0
Silt	PR = 3.22 (CF%) + 12.0
Clay	PR = -0.79 (CF%) + 121.0
Till	PR = -3.05 (CF%) + 327.1
All	PR = -0.479 (CF%) + 130.0

8.5 PERMAFROST

Permafrost conditions were not always identified on the field ditch logs. In addition, it was difficult to ascertain the difference between seasonal frost and permafrost. Therefore, for purposes of this study, the percentage of permafrost occurrence along the route as determined by geophysics was correlated against production rate as shown in Figure 32. The correlation with production rate being the dependent variable (Line A) seemed more reasonable and was selected. This correlation is somewhat disturbing in that it suggests that permafrost terrain is easier to trench than unfrozen terrain. This is likely a reflection of the overwhelming affect of seasonal frost on production rates which masks the effects of permafrost. This will be discussed further in a later section.

9.0 MODELS

The ultimate purpose of developing any correlations between soil parameters and production rate for ditching would be to establish a predictive tool(s) so future pipelines could be cost estimated and designed more effectively. It was hoped several levels of predictive tools or models could be developed in this study for different levels of expense and confidence. For example, if a correlation of production rate could be established by terrain analysis alone, a lot of expense in drilling could be saved initially. If other correlations with soil parameters or moisture content were found to be better predictive tools, this could represent a high level of effort and money to estimate production rates with higher confidence.

Therefore, six models based on different parameters as highlighted below were investigated and the results presented in the following sections.

1. Model I - Terrain Type
2. Model II - Soil Type
3. Model III - Moisture Content
4. Model IV - Cobble Frequency
5. Model V - Moisture Content and Cobble Frequency
6. Model VI - Permafrost.

For purposes of this study, the pipeline route was examined in 10 km intervals and soil and other conditions averaged over those intervals.

9.1 MODEL I - Terrain Type

The simplest level of information often available for pipeline routing, prior to the drilling of many boreholes, is terrain typing. Land forms can be identified by aerial photographs and brief field reconnaissances. The cost of this level of investigation is generally substantially less than a drilling program. In addition, a much more general area can be examined using this method as opposed to the very local nature of a drilling program which is comprised of very small diameter boreholes spaced at large intervals.

Terrain information was averaged over 10 kilometer intervals based on the dominant terrain type encountered. The average ditch production rate from Figure 19 was then applied to these intervals and a prediction of average production along the pipeline determined. The predicted production rates are shown plotted against the actual production rates in Figure 33. As can be seen, this terrain type model approximates some trends in the data, but is very "damped" in that it cannot predict variations in production rate within a terrain unit itself.

9.2 MODEL II - Soil Type

The next level of information often available for a pipeline route is soil classification. Boreholes which have no to very little testing data are sometimes available near pipeline routes which may have been drilled for some other purpose such as a highway investigation or as part of a soil survey for agricultural or environmental purposes. In these cases, a correlation between soil type and ditch production may be more useful than by terrain type.

A model was developed similar to the terrain type model that was based on the average production rates shown in Figure 20. The predicted ditch production is shown plotted against the actual production for 10 kilometer intervals in Figure 34. As can be seen, the prediction is rather crude and does not fit the data exceptionally well.

9.3 MODEL III - Moisture Content

The highest level of data that might be available for a large pipeline is detailed borehole information along the route. Often the most common soil test undertaken is natural moisture content determination. Moisture content data was averaged and summarized for the dominant soil type for 10 kilometer intervals along the pipeline route. Soil data was determined from the borehole databank, but was interpreted slightly before being used directly. In areas of lacustrine soils, the difference between silts and clays was often up to the discretion of the person classifying the soil. To alleviate this problem, silts and clays were grouped together in this study. Three soil groups were classified for this portion of the study; sands and gravels, silts and clays, and tills. A weighted average of moisture content was also established for each 10 kilometer interval.

The results of the moisture content model predictions are shown plotted against the actual production in Figure 35. The correlation is much better than those based on soil and terrain type alone. Local icy or dry areas are identified by being easy or more difficult to ditch. This type of model allows variations in ditch production rate within a terrain or soil unit and the results are not "damped".

9.4 MODEL IV - Cobble Frequency

As mentioned in earlier sections, the determination of cobble frequency was very difficult to quantify. In this study, two means of assessing cobble frequency came from the bedding criteria and occurrence in test boreholes. Figure 36 shows the relationship which exists between cobble frequency based on bedding criteria and boreholes averaged for 10 kilometer intervals along the pipeline route. As can be seen, a very rough correlation between the two exists. For the purposes of our study, this correlation has been adopted for comparing cobble frequency between the two criteria.

Rough correlations between production rate and cobble frequency were presented in Section 8.4 As some of the correlations were not reasonable, one correlation was assumed for all soil types as shown in Figure 31. Cobble frequency data was summarized for both the bedding criteria and borehole criteria for 10 kilometer intervals along the pipeline route. The borehole cobble frequency was adjusted to the bedding criteria by the correlation presented in Figure 36. Both cobble criteria were then correlated to production rate based on the correlation shown in Figure 31. The results for both are presented in Figure 37. Both curves are not bad approximations to production rate but are somewhat averaged or "damped".

The next step was to attempt to improve both the moisture content and cobble frequency models by considering both variables at once. The results are presented in the following section.

9.5 MODEL V - Moisture Content and Cobble Frequency

In order to improve on the overall correlations, a combination of effect by cobble frequency and moisture content was considered. Various weightings of each factor was considered as shown in Table 6 below.

TABLE 6 - MOISTURE CONTENT/COBBLE FREQUENCY WEIGHTING

Case	Cobble Frequency Correlation (%)	Moisture Content Correlation (%)
A	30	70
B	50	50
C	70	30

The results are shown in Figures 38, 39 and 40 for cases A, B and C, respectively. It would appear the addition of the cobble correlation does not dramatically improve the moisture content correlation alone. A general "damping" effect is noticeable as more effects of the cobble correlation is introduced.

9.6 MODEL VI - Permafrost

An attempt to correlate permafrost occurrence against actual production was undertaken based on the somewhat contradictory correlation presented in Figure 32. The results are presented in Figure 41 and are not a very close approximation to the data.

It is highly likely the effects of permafrost are not very important to this study because seasonal frost extended over much of the depth of excavation. Whether the ground was permafrost or seasonally frozen may not be very significant. This possibly explains the somewhat poor correlations observed.

10.0 GENERAL FACTORS INFLUENCING DITCH PRODUCTION

Many of the factors which influenced the overall ditch production could not be analyzed analyzed quantitatively in this study. This section deals with some of the more qualitative aspects of construction which may have had more influence on production than soil conditions.

10.1 WEATHER

Most of the pipeline was constructed during the middle of winter. Access was not possible until substantial frost had penetrated the ground surface. Temperatures were often between -30 and -40°C. During these cold periods, production was generally much slower for two reasons; equipment is more prone to breakdowns, and repairs and general working was slower as much time is spent by workers on keeping warm.

Temperatures above -25°C, which are still quite cold, seemed easier to work in as breakdowns were less frequent and it was easier for people to stay warm.

10.2 THICK ORGANICS

The presence of thick peat bogs caused substantial downtime to both backhoes and ditching machines. In a very local area near KMP 130, both a 245 Caterpillar backhoe and one of the ditching machines broke through the thin frost layer and became badly stuck. In both cases, days were lost when major repairs were required to thaw and dry out the equipment. This particular area could have been avoided as it was visible on the aerial photographs as a thick organic zone. The expense of routing around the peat bog likely would have been minor in comparison to the lost time and production experienced. These incidents highlighted the importance of terrain analysis and indicate how trouble areas can often be avoided by careful route selection.

10.3 TILLS WITH BOULDERS

The tills found along the Mackenzie Valley are often moderately fine grained and are more difficult to excavate than lacustrine silts and clays as this study has shown. However, the true significance of cobble or boulder occurrence within a till unit could not be fully determined. Observations by ditch inspectors however, suggest that the area immediately north of the Mackenzie River crossing was a very coarse grained till. Large cobbles and boulders were so frequent, the ditching machines literally could not excavate the material. The clay till matrix was very strong, and boulders would be held so tightly, that in some instances the wheel would literally shear granite boulders in half, rather than shear the clay matrix.

Until a better means is developed of estimating cobble frequency, only a qualitative assessment of bony tills can be made that they are extremely difficult or impossible to excavate with normal ditching machines.

10.4 MOISTURE CONTENT - SANDS

During excavation of the pipeline trench near the Great Bear River crossing, it was observed by field inspector Mr. Alex Costin, that certain sands were extremely difficult to excavate. In fact, special hardened ditching teeth were required to excavate this area. Visually there was nothing special about the appearance of these soils, nor was there anything unusual about their apparent origin that may explain the difficulties in excavation. Although the borehole data was insufficient to prove anything conclusively, it is speculated at this time that the likely cause of the difficulty in ditching was a moisture content that was low enough to produce a well-bonded ice structure with all sand particles in contact with each other, but with no excess ice.

Similar difficult ditching conditions in sands were encountered at two other locations along the pipeline route.

11.0 CONCLUSIONS

The results of this study suggest that there are means of estimating the ditch production rate from soils and terrain data, but the correlations are fairly rough. Estimates of actual production and logistics likely introduced significant errors in this study which unfortunately were unavoidable. However, the following conclusions can still be made:

- In general, terrain units reflecting till soils are twice as difficult to ditch as lacustrine soils.

- Moisture content appears to be an important variable and a reasonable estimate of ditchability can be made using it alone.

- Cobble frequency is an important factor affecting ditchability, but the means to quantify this parameter is difficult. Attempts to improve moisture content and soils correlations with the influence of cobbles were not highly successful.

- Permafrost is not a highly significant variable when winter construction is adopted. The seasonal depth of frost penetration may often be greater than pipe burial depth and all ground therefore behaves frozen.

The results of this study are promising that some good predictive tools may be developed for future pipelines, if the opportunity arises for closer documentation of ditch production rates on the next major pipeline. It would be useful to collect much more detailed production rate information, which could be collected by the ditch inspector with no additional cost to the owner or contractor.

REFERENCES

1.) Hanna, Saunders, Lem and Carlson, "Alaska Highway Gas Pipeline Project (Yukon) Section - Thaw Settlement Design Approach", Fourth International Permafrost Conference, 1984.

2.) Hardy Associates (1973) Ltd., "Delineation of Permafrost Distribution by Geophysical Survey - Volumes I to VI", November 1982.

3.) Hardy Associates (1978) Ltd., "Thaw Settlement Design Values for KMP 0.00 - KMP 868.30", December 1982.

4.) Lyon, A.J., "Dealing with Data", Pergammon Press, New York, 1970.

5.) UMA, Canuck, Hardy (UCH), "Daily Progress Reports" 1983 - 1985.

6.) UMA, Canuck, Hardy (UCH), "Field Diaries" 1983 - 1985.

7.) UMA, Canuck, Hardy (UCH), "Field Ditch Logs" 1983 - 1985.

APPENDIX A

FIGURES

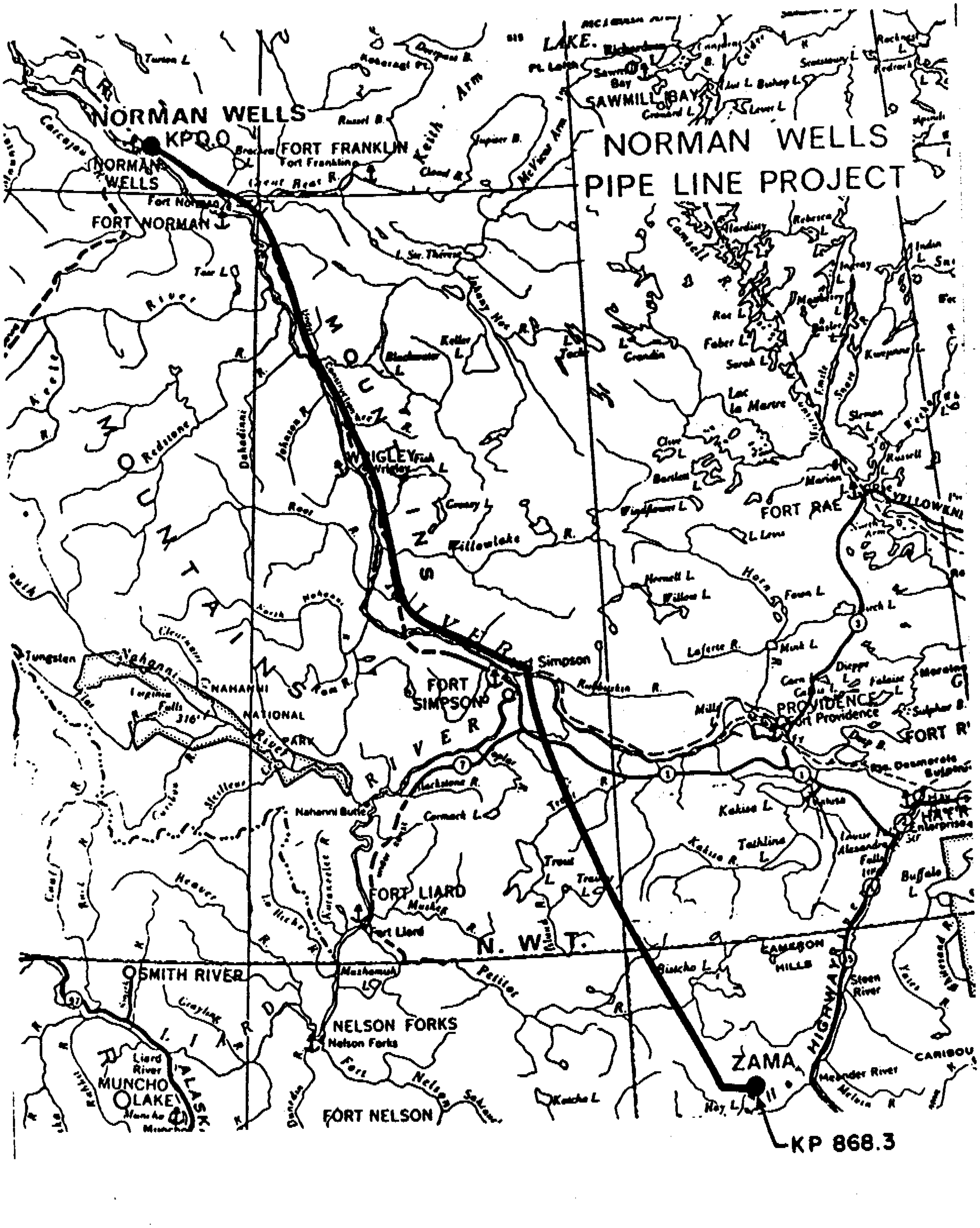


FIGURE 1 LOCATION PLAN

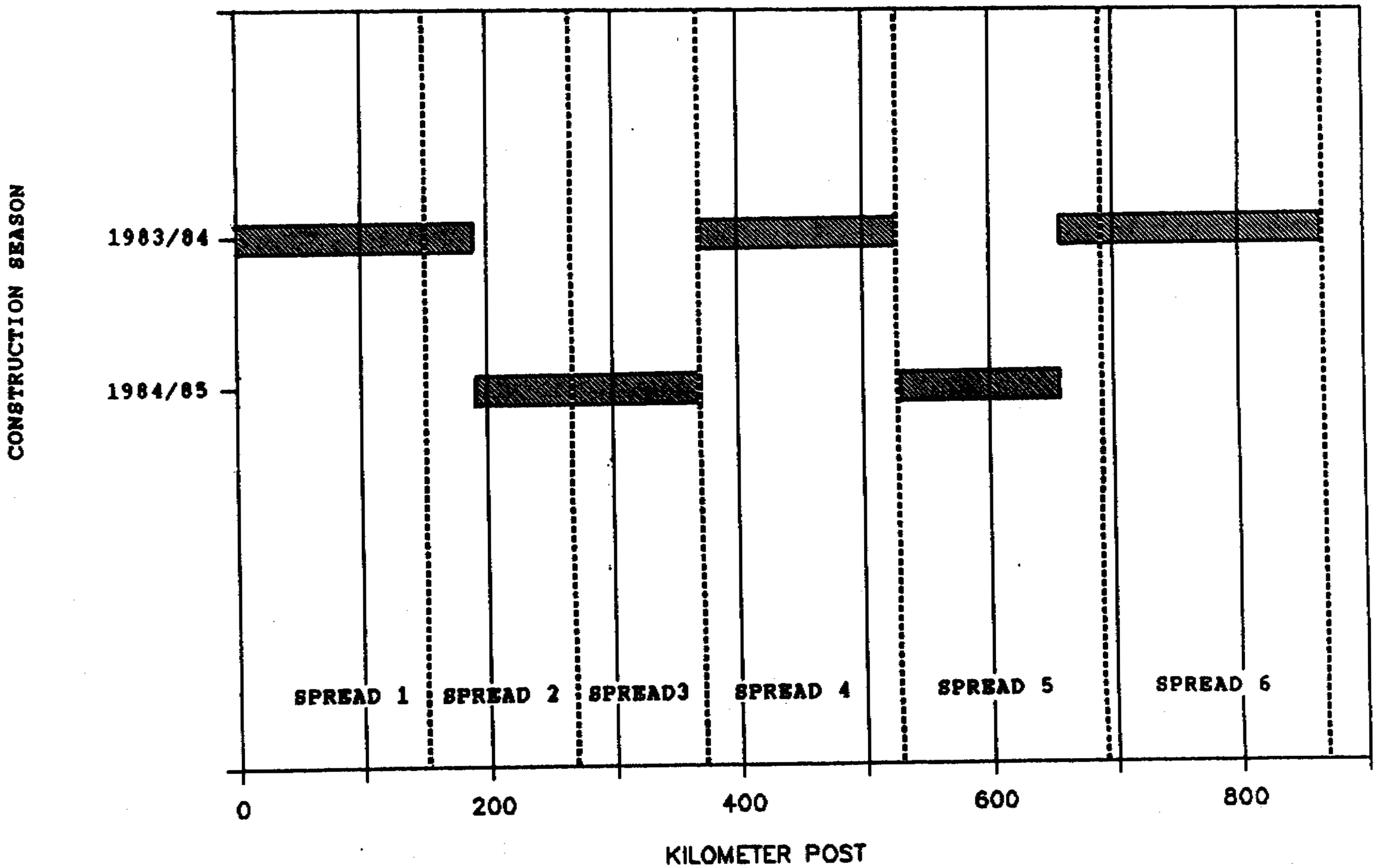


FIGURE 2 CONSTRUCTION SCHEDULE

From: U
To: IPL

14-FEB-1984 07:19

INTERPROVINCIAL PIPE LINE (NW) LTD.
PIPE LINE PROJECT
DAILY CONSTRUCTION REPORT
SPREAD NO. 1 REPORT NO.: 55

FOR PERIOD: 2/13/84
TO PERIOD: 2/13/84

REPORT DATE: 2/14/1984

ITEM NO.	ITEM DESCRIPTION	UNIT	PREVIOUS TOTAL QUANTITY	QUANTITY THIS PERIOD	TOTAL QUANTITY TO DATE	TARGET QUANTITY TO DATE	QUANTITY TO GO	% VAR	AVG PROD TO DATE (Km/day)	AVG PROD TO COMP (Km/day)
101	GRADING	km	190.0	0.0	190.0	117.6	6.0	61	2.8	0.3
102	STRING	km	109.0	5.0	114.0	74.8	82.0	52	4.1	2.4
103	TRENCH	km	36.9	5.0	41.9	57.0	154.1	-26	2.2	4.0
105	WELDING	km	84.4	4.0	88.4	69.2	107.6	27	4.0	3.3
106	LOWERED IN	km	28.1	3.5	31.6	48.1	164.4	-34	1.7	4.1
109	TIE INS	km	25.3	0.0	25.3	43.9	170.7	-42	1.3	3.8
112	CLEAN UP	km	6.6	0.0	6.6	38.0	189.4	-82	3.3	3.5

NO. OF WELDS:	400	TO DATE:	5017
NO. OF REPAIRS:	468	TO DATE:	925
NO. OF CUT OUTS:	4	TO DATE:	90

WELDING PERFORMANCE REPORT
FOR: 2/13/1984

	NO. OF X-RAYS	ACCEPTED	REJECTED	NO. OF REPAIRS	NO. OF CUT OUTS	% REJECT RATE
TODAY:	158	119	39	39	0	24.7
TO DATE:	4564	3312	1262	1103	159	27.7

COMMENTS

WEATHER: FIRST BREAK, HI-24, LO-30, CLEAR
ALL PHASES OF JOB WENT ALONG WELL TODAY. DITCH IN BETTER SOIL.
TEMPERATURE WARMER WITH LESS WIND PROVED BETTER FOR WELDING.
CLEAN-UP CREW BUSY IN CANYON CREEK. BUILDING CRIBING AT THE
FAMOUS BOSWORTH CREEK.
NOTE: ADJUSTED TIE-INS BY -1.3km FOR TRUE CHANAGE LOCATION

FIGURE 3 TYPICAL PROGRESS REPORT

UMA • CANUCK • HARDY
CONSTRUCTION SERVICES MANAGER

INTERPROVINCIAL PIPE LINE (NW) LTD.
NORMAN WELLS TO ZAMA PIPE LINE

FR-026
DAILY DITCH LOGS
Page ____ of ____

LOCATION: Spread #1 LOCATION CODE: 11
CONTRACTOR: PE BEN CONTRACT NO.: ____ DATE: Mar 3/84
WEATHER: TEMPERATURE: -25 Overcast; calm CONDITION: ____

CHAINAGE * MIN. EVERY 100 METERS	PEAT THICKNESS (cm)	MINERAL SOIL THICKNESS (cm) AND TYPE (FINE COARSE)	IF DITCH DEPTH 1.17m 1.32 RECORD DEPTH EVERY 30m PEAT + MINERAL	COBBLES ** FOR BEDDING CRITERIA (YES, NO)	TRENCH BOTTOM (FROZEN, UNFROZEN)	COMMENTS
130+600	1.2	0% F C	1.2	Y N	F UF	Pt; brown Vx 20%/50m from - water in trench / stuck ditcher
130+700	1.2	0% F C	1.2	Y N	F UF?	Pt; brown trench full of water
130+800	0.3	70% F C	1.2	Y N	F UF	Grey brown sand Nbe some Vs 10-20%
130+900	0.5	40-50 F C	1.15	Y N	F UF	Grey & Brown Sand Nbn + Nbe light seepage in trench
131+000	0.5-0.8	20-40% F C	1.2	Y N	F UF	Pt Vx 20% Grey Sand Nbn + Nbe
131+100	0.2-0.8	20-80% F C	1.2	Y N	F UF?	Variable Pt thickness / trench half full Grey Sand Nbn + Nbe / water
131+200	All	0% F C	?	Y N	F UF?	Fibrous light brown - Pt prob UF - ditch full of water!
131+300	0.2-0.4	60-80% F C	1.2	Y N	F UF	Gray + light brown Sand Nf + Nbn
131+400	1.2	0% F C	1.2	Y N	F UF?	Peat light brown 20m UF - trench w/water
131+500	1.2	0% F C	1.2	Y N	F UF	Peat light brown Nbe
131+600	0.15	85% F C	1.15	Y N	F UF	light yellow silt Nf + Nbn dk brown sand Nf
131+700	0.2-0.4	65% F C	1.2	Y N	F UF	Pt. incl. Brown sand Nbn
131+800	0.15	85% F C	1.2	Y N	F UF	Brown sand, little silt Nbn
131+900	0.3	65-70% F C	1.2	Y N	F UF	Brown/grey sand Nbn
132+000	All	0% F C	?	Y N	F UF?	Brown pt. - UF probably Trench full of water
132+100	0.1	70% F C	1.15	Y N	F UF	Light brown Sand Nf
132+200	0.2-0.4	65-80% F C	1.1	Y N	F UF	Grey/brown sand Nf + Nbn
132+300	0.15	85% F C	1.2	Y N	F UF	Grey/brown Sand Nbn
132+400	0.20	80% F C	1.2	Y N	F UF	" " + water
132+500	1.2	0% F C	1.2	Y N	F UF	Pt light brown + water

* AT 100m INTERVALS AND INTERMEDIATE POINTS OF SIGNIFICANT CHANGE.

** CLAUSE 7.4.1.10 TO APPLY WHEN TWO OR MORE 150 mm DIA. PLUS COBBLES PRESENT IN 10m OF DITCH AND TO REMAIN IN EFFECT UNTIL NO SUCH COBBLES PRESENT FOR 50m OF DITCH.

SIGNED [signature] CHIEF INSPECTOR SIGNED Robert Saunders INSPECTOR

PRINTED ____ PRINTED Robert Saunders

FIGURE 4 TYPICAL DITCH LOG

BOREHOLE NUMBER : UMDP385B
KILOMETER POST : 202.10
OFFSET : 1.02
TERRAIN TYPE : LP

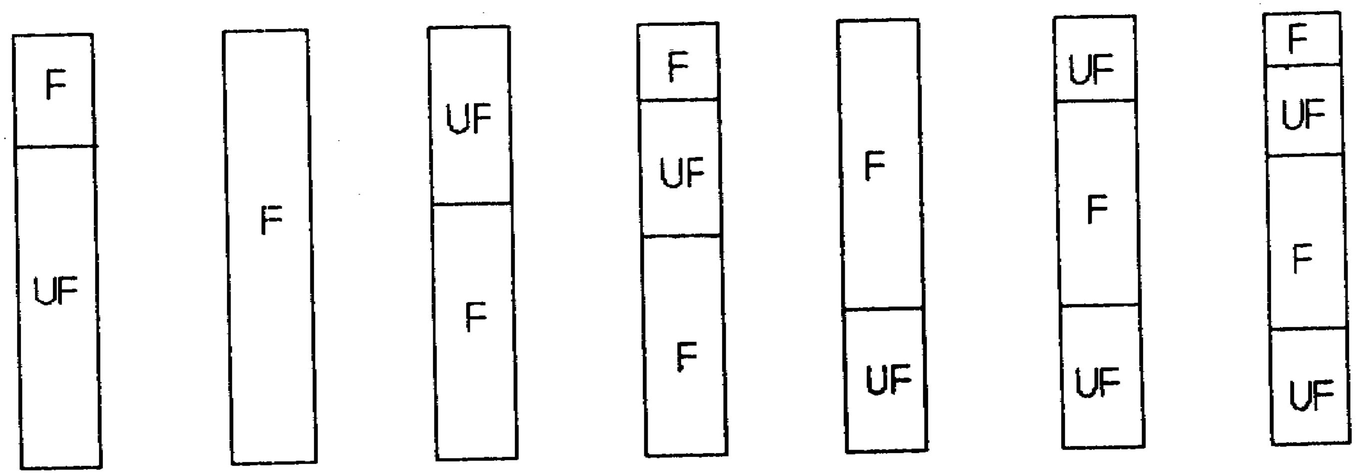
DEPTH OF HOLE : 20
DEPTH OF PEAT : 0
DEPTH TO BEDROCK: 100
DEPTH OF P.FROST: 9
DEPTH OF THAW : 0
DEPTH TO TILL : 9

COBBLES :
LIMITS :
GRAIN SIZE:
STRENGTH :

DEPTH	BH	USC	MC	VI	PF	PT	TL	BR
0								
	*	CL	35	5	##			
2	*				##			
	*	CL	35	5	##			
4	*				##			
	*				##			
	*	CL	35	5	##			
7	*				##			
	*				##			
	*	CL	15	-1	##			
10	*				..		TL	
	*				..		TL	
	*				..		TL	
	*	GC	13	-1	..		TL	
	*				..		TL	
15	*				..		TL	
	*				..		TL	
	*				..		TL	
	*	GC	11	-1	..		TL	
	*				..		TL	
20	*				..		TL	
30								
40								

FIGURE 5 TYPICAL BOREHOLE LOG - IPL DATABANK

IPL DATABANK - CODING FOR PERMAFROST



DEPTH OF PERMAFROST	100	100	100	100	#	#	#
DEPTH OF THAW	100	0	#	#	0	#	#

FIGURE 6 CODING FOR PERMAFROST - IPL DATABANK

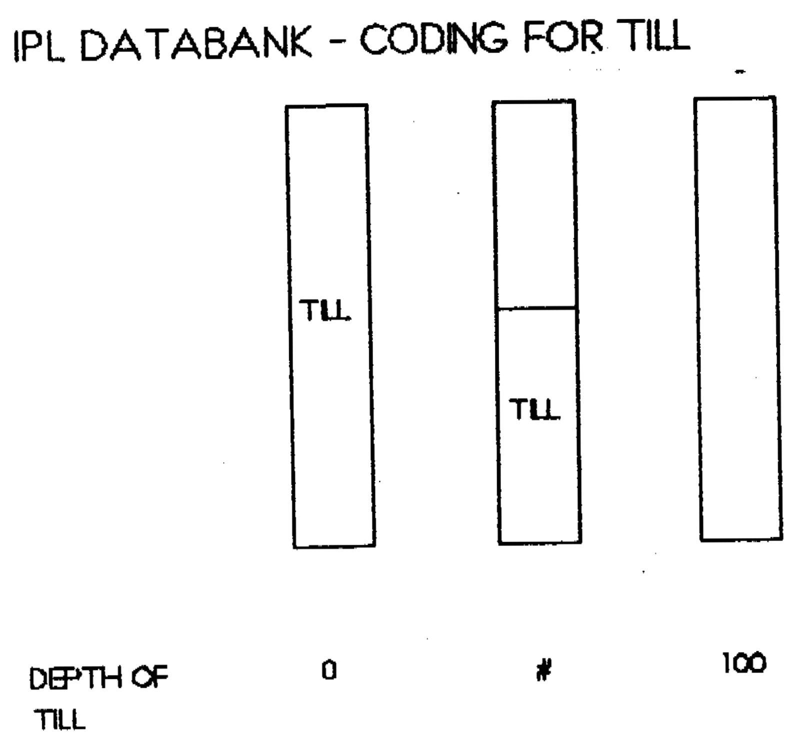


FIGURE 7 CODING FOR TILL - IPL DATABANK

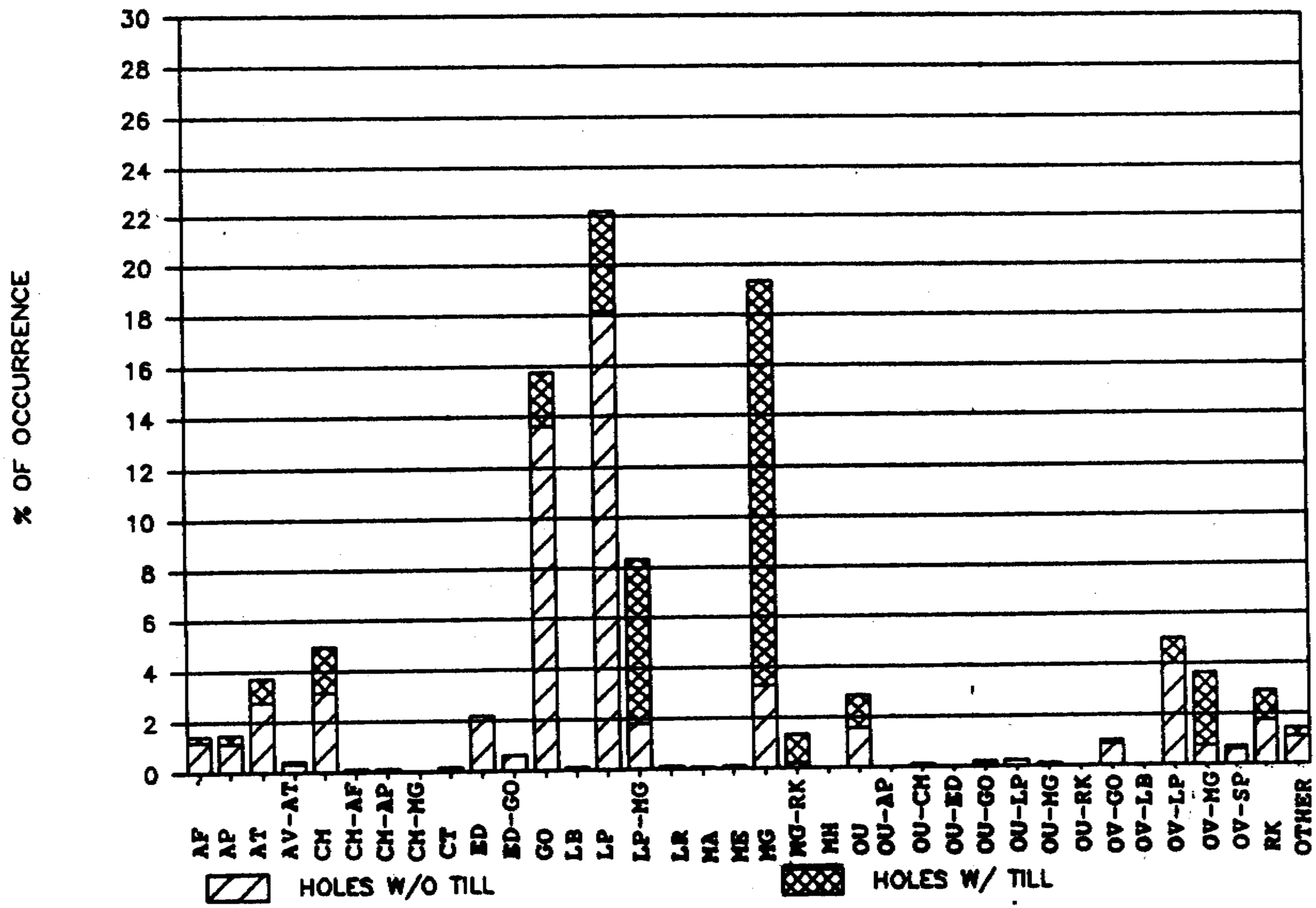


FIGURE 8 TILL OCCURRENCE BY TERRAIN TYPE (PERCENTAGE OF TOTAL)

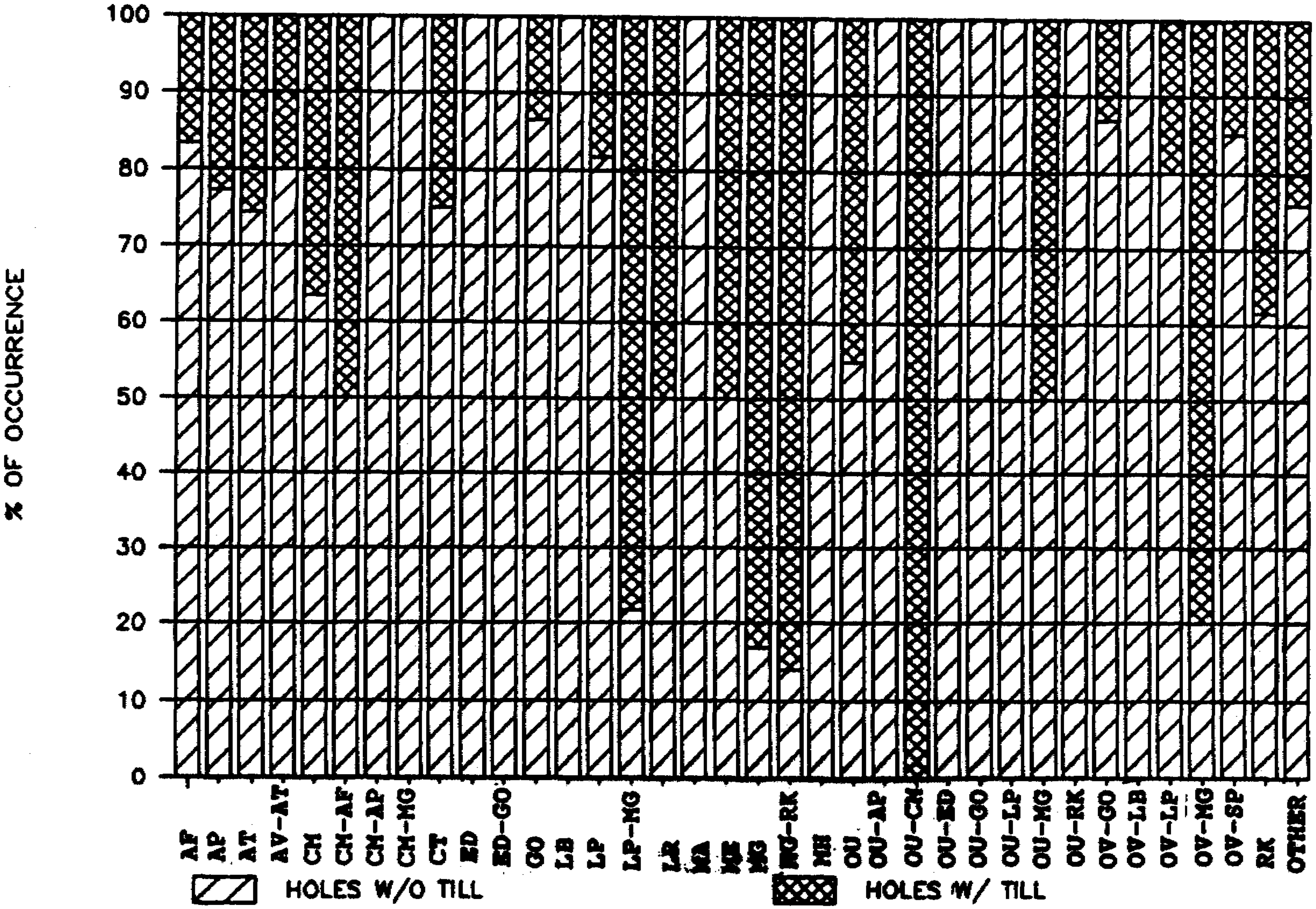


FIGURE 9 TILL OCCURRENCE BY TERRAIN TYPE (PERCENTAGE OF EACH UNIT)

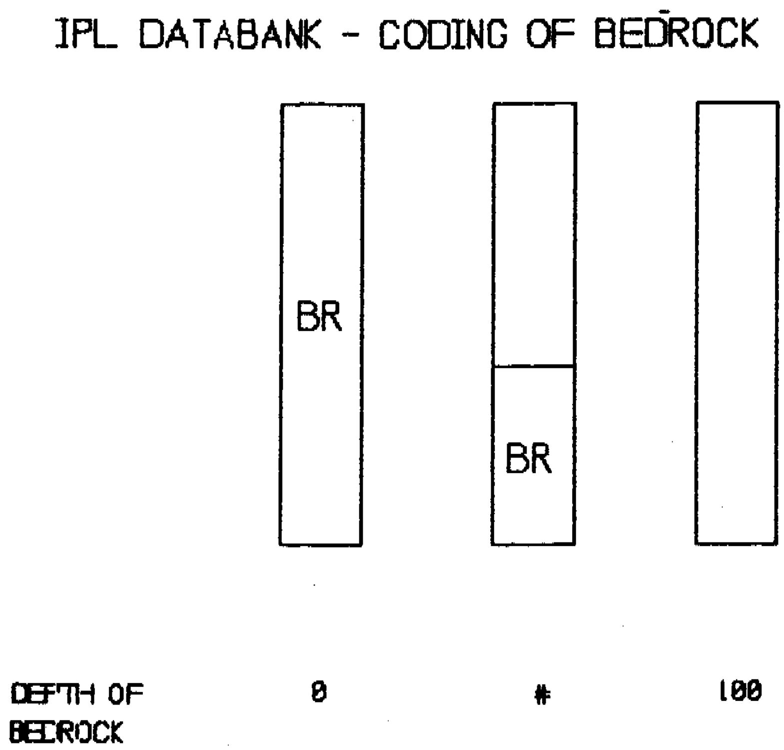


FIGURE 10 CODING FOR BEDROCK - IPL DATABANK

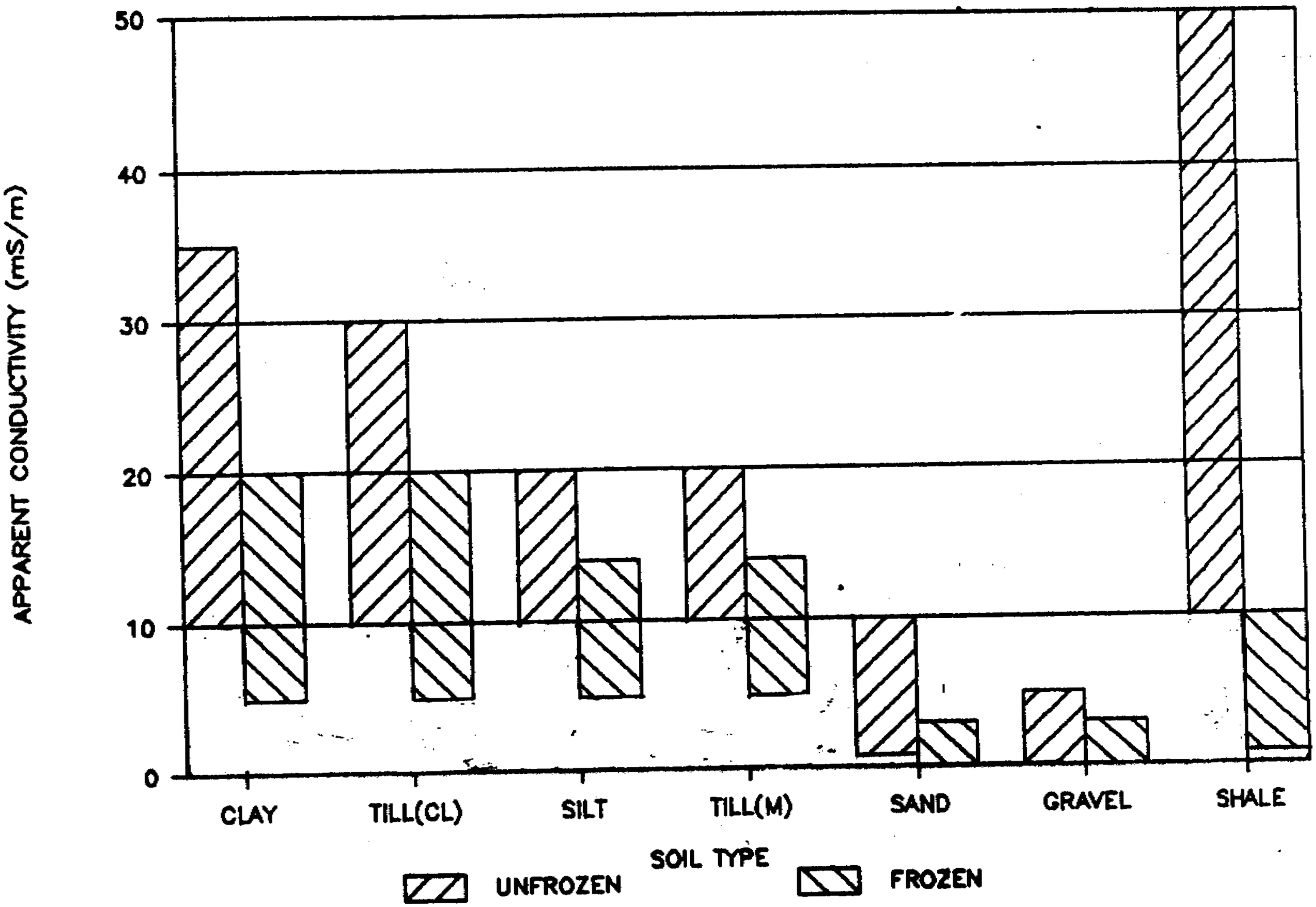


FIGURE 11 APPARENT CONDUCTIVITY RANGES

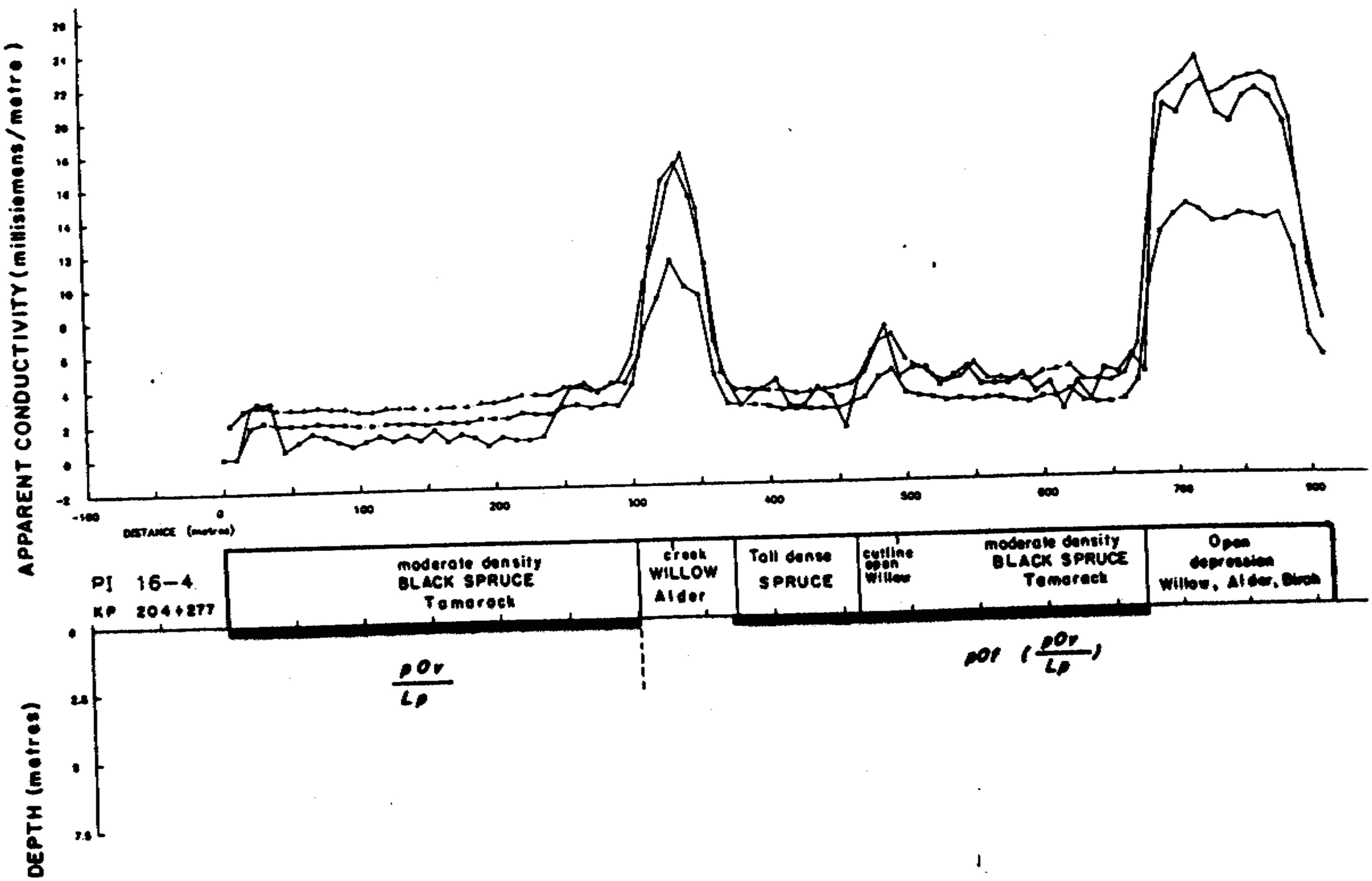


FIGURE 12 APPARENT CONDUCTIVITY - FROZEN/UNFROZEN INTERFACE (UNIFORM SOIL)

- from Hardy Associates (1978) Ltd. (Reference No. 2)

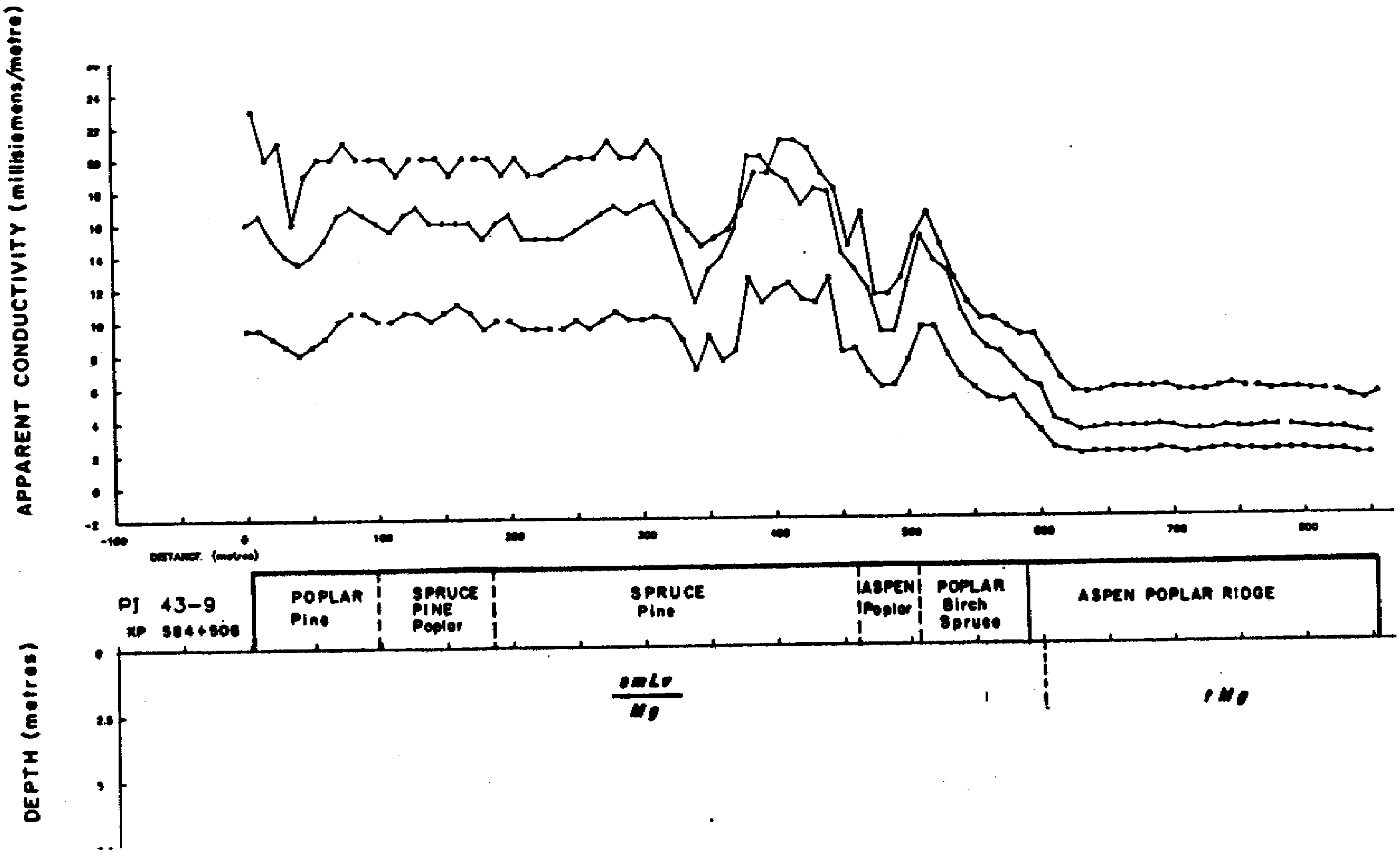


FIGURE 13 APPARENT CONDUCTIVITY - TERRAIN TYPE INTERFACE (UNFROZEN SOIL)

- from Hardy Associates (1978) Ltd. (Reference No. 2)

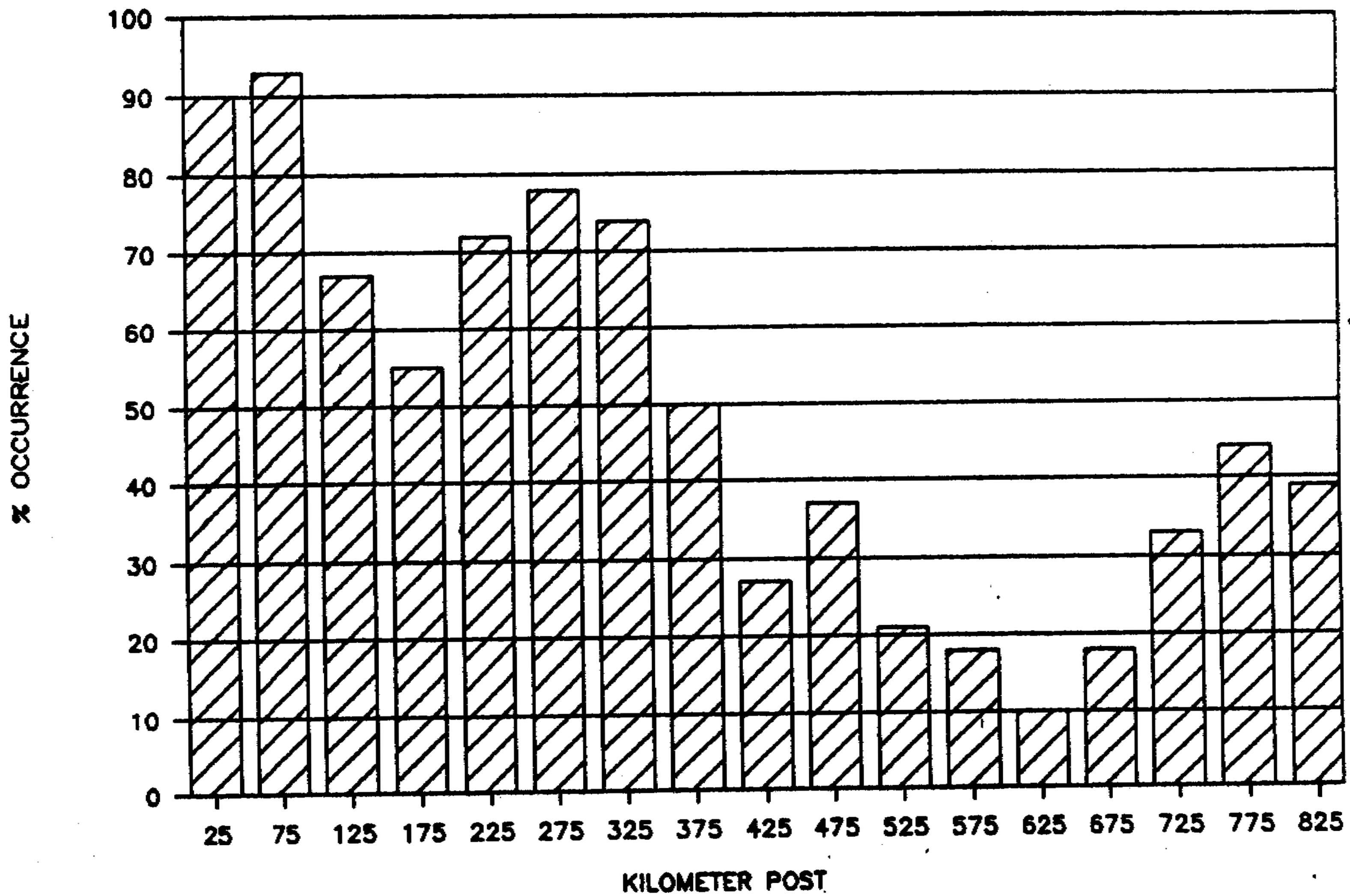


FIGURE 14 PERMAFROST DISTRIBUTION BY CONTINUOUS GEOPHYSICS

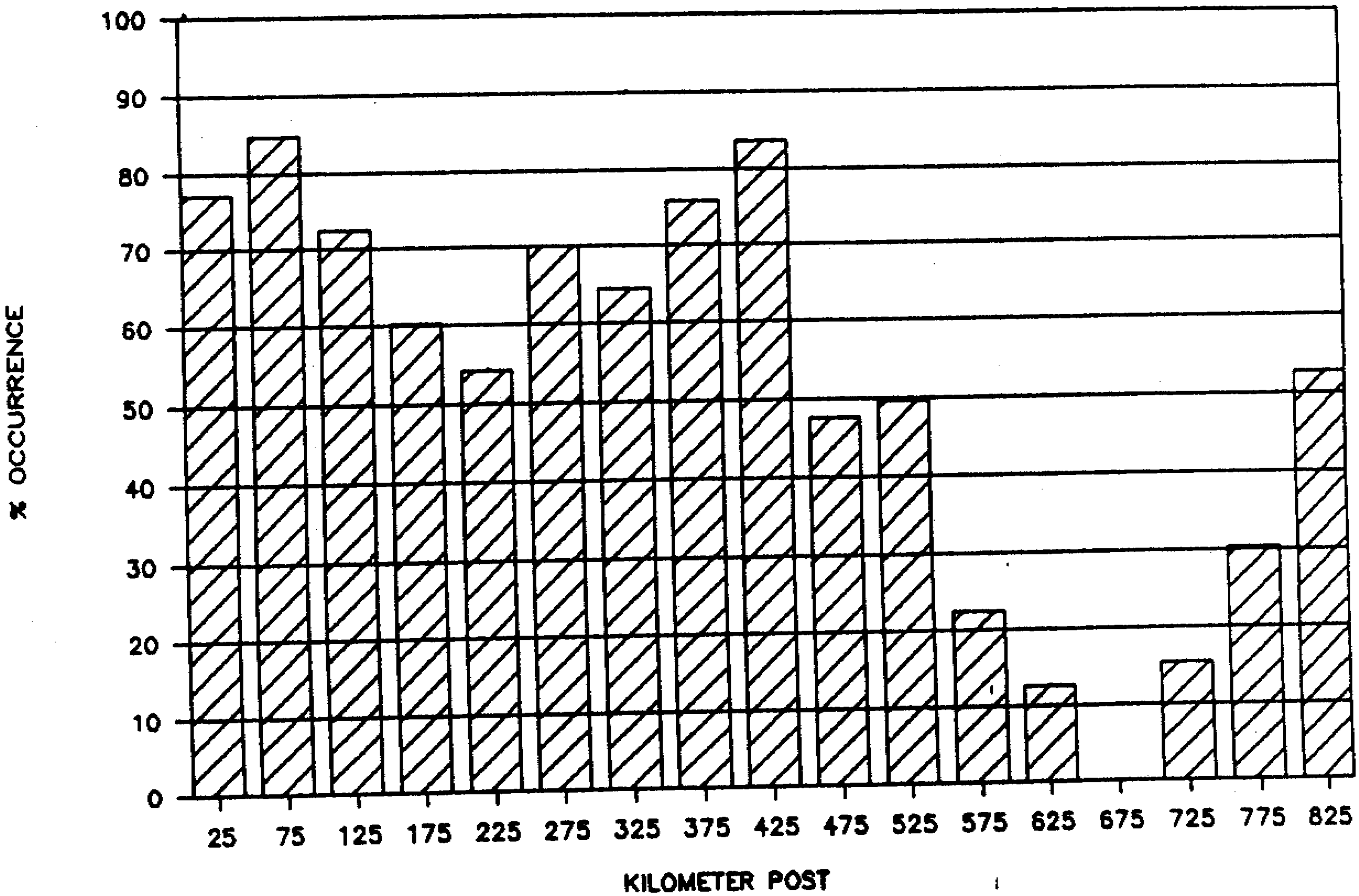


FIGURE 15 PERMAFROST DISTRIBUTION BY BOREHOLE

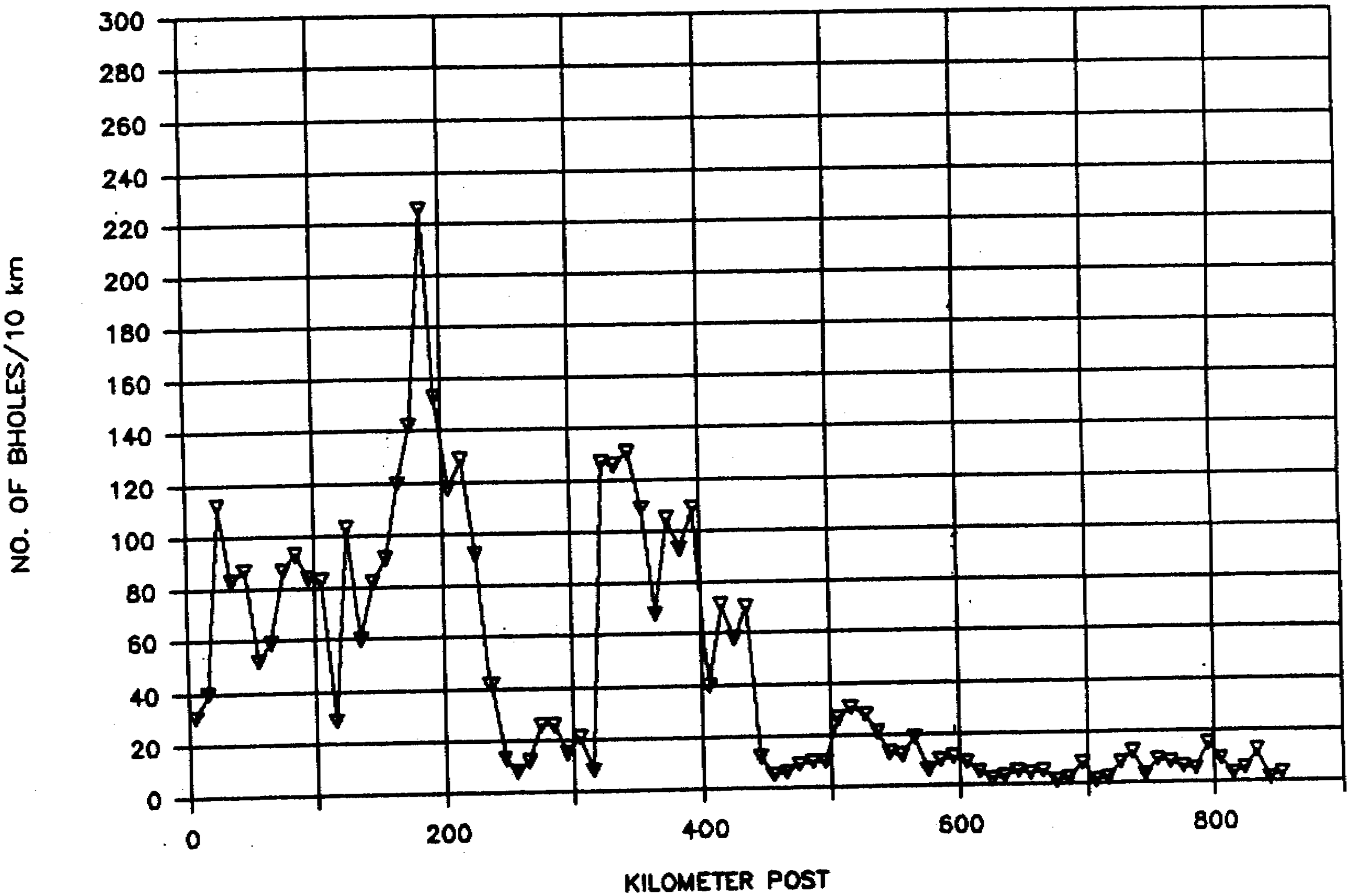


FIGURE 16 BOREHOLE FREQUENCY

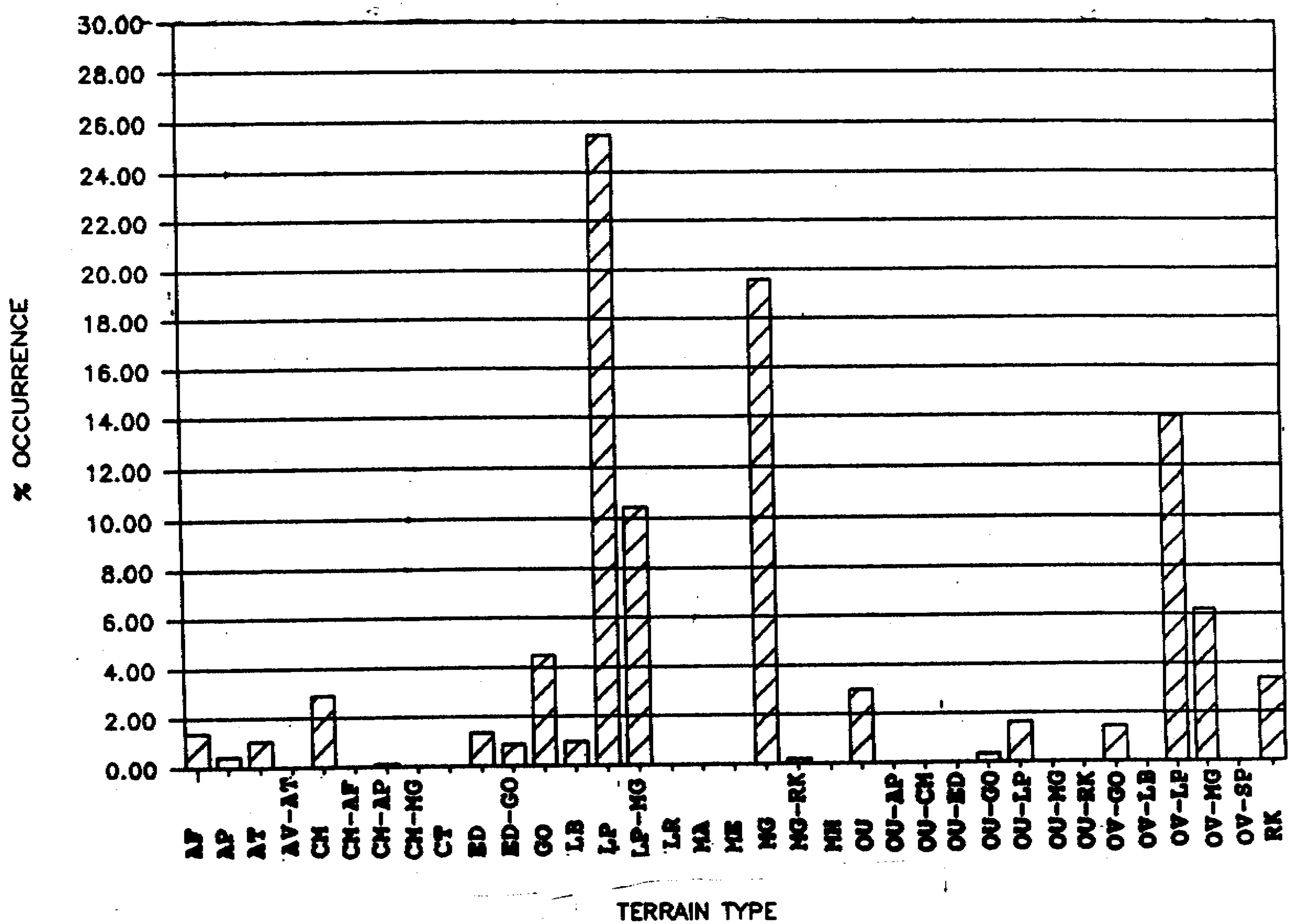


FIGURE 17 TERRAIN TYPE FREQUENCY

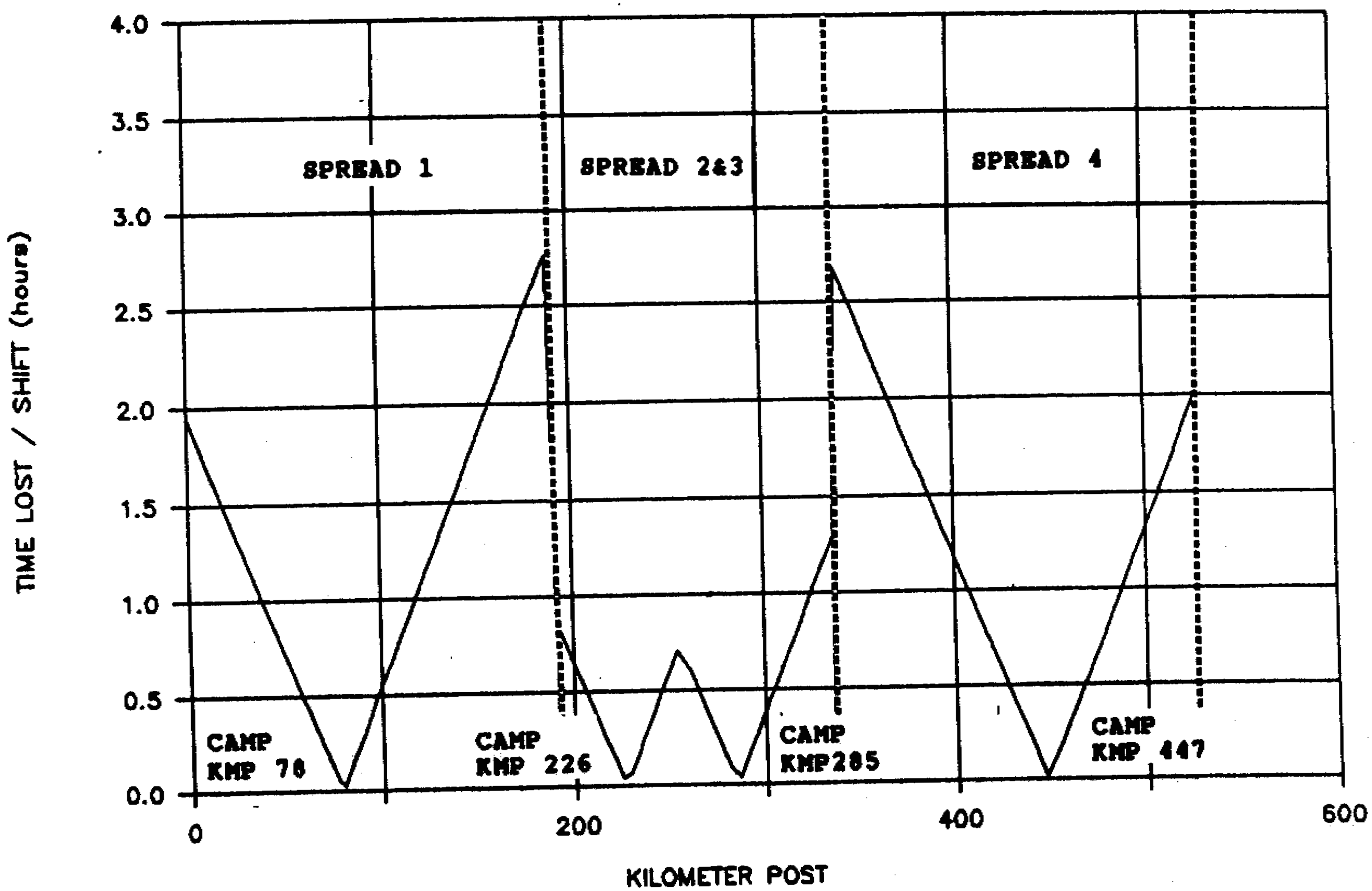


FIGURE 18   TIME LOST PER SHIFT DUE TO CREW TRAVEL

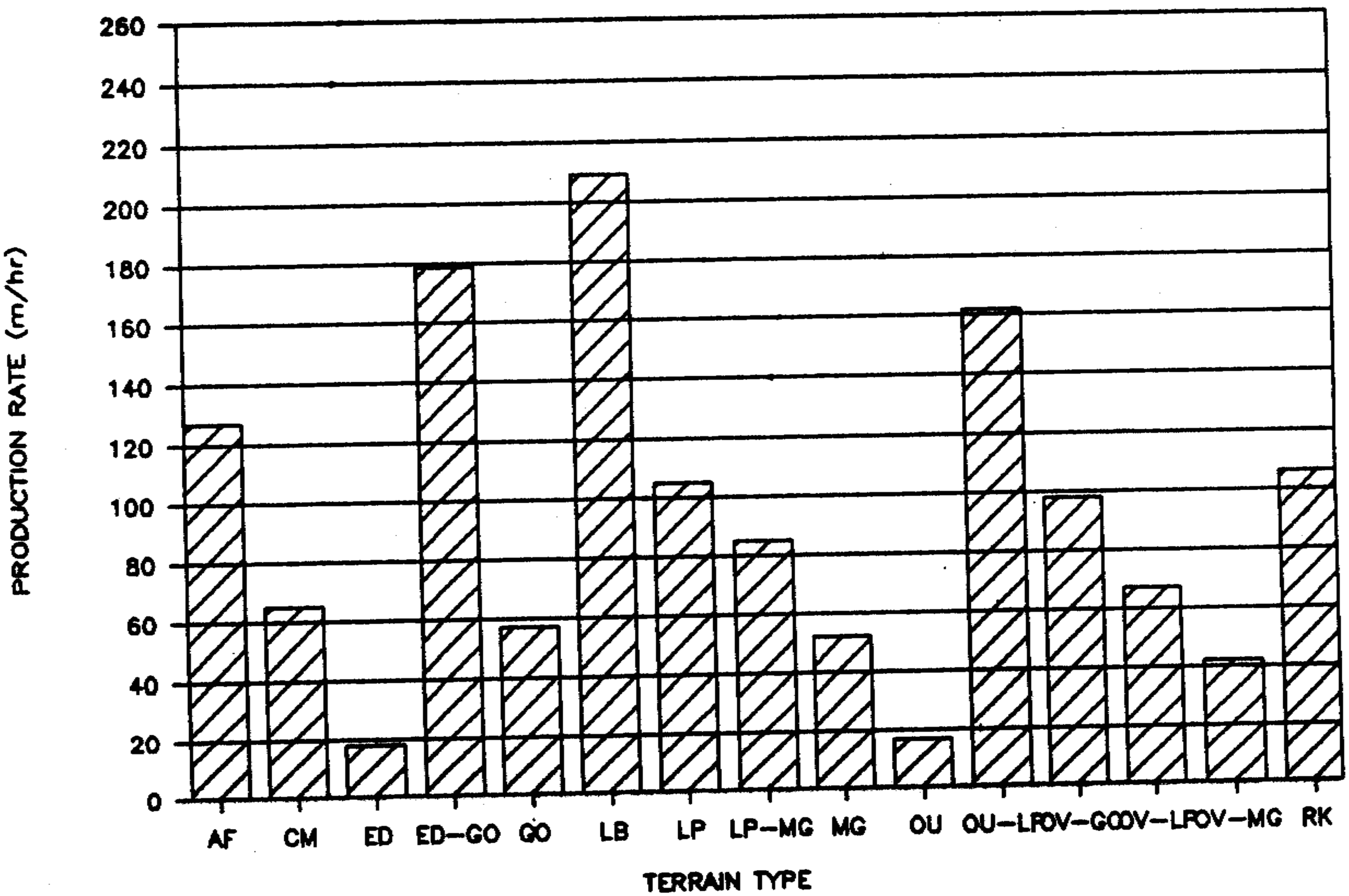


FIGURE 19 DITCH PRODUCTION vs TERRAIN TYPE

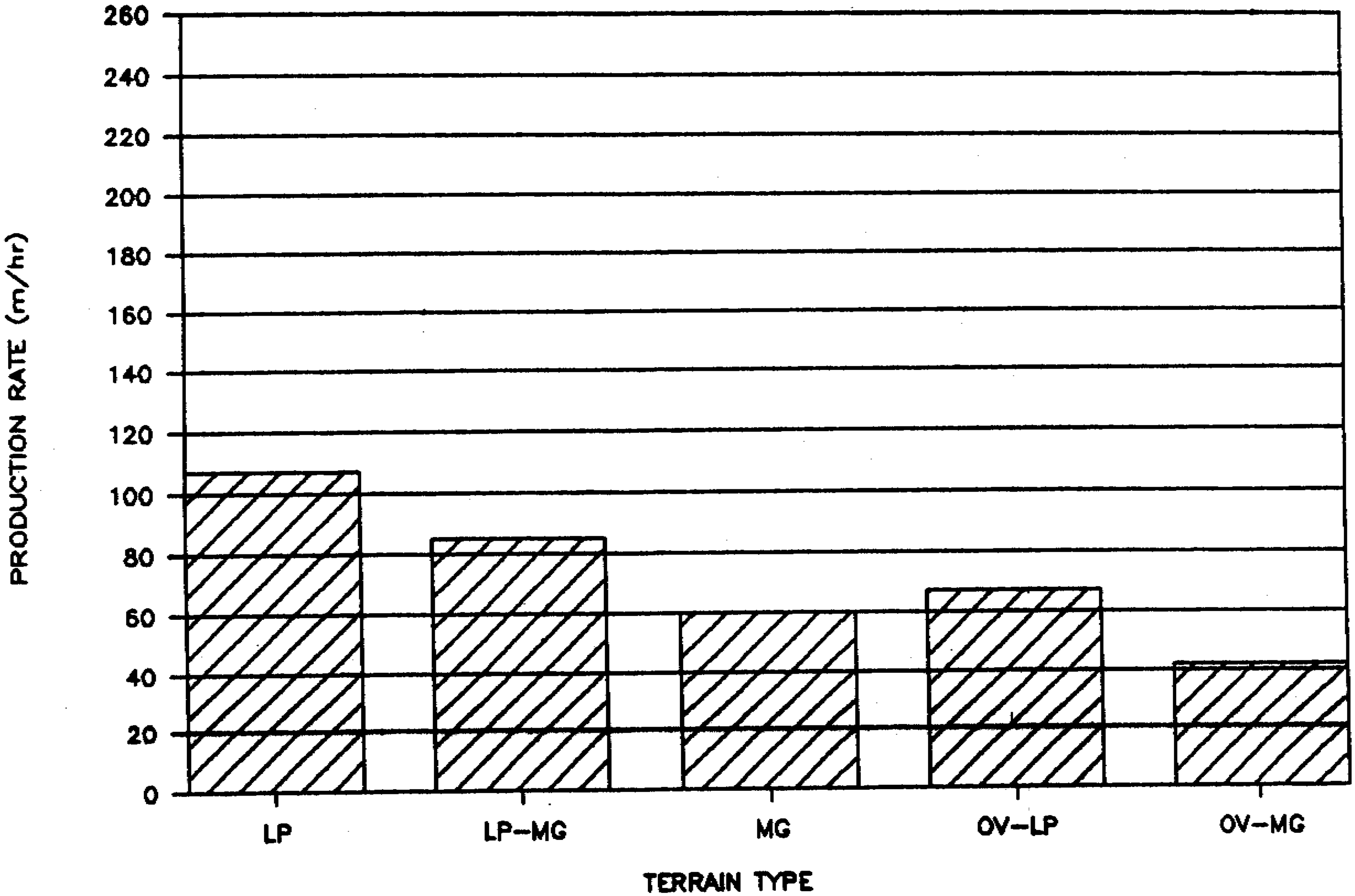


FIGURE 20 DITCH PRODUCTION vs DOMINANT TERRAIN TYPES

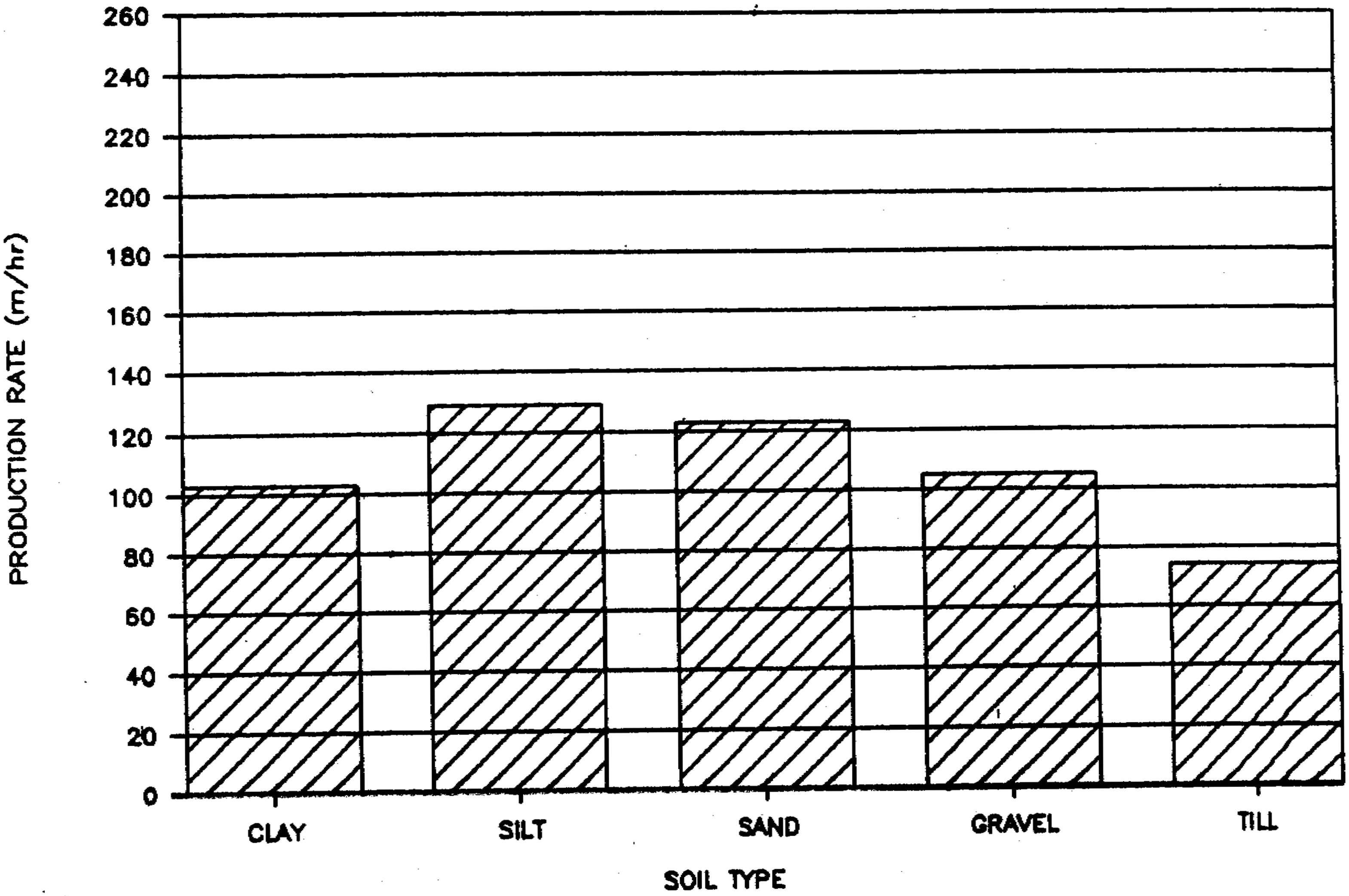


FIGURE 21 DITCH PRODUCTION vs SOIL TYPE

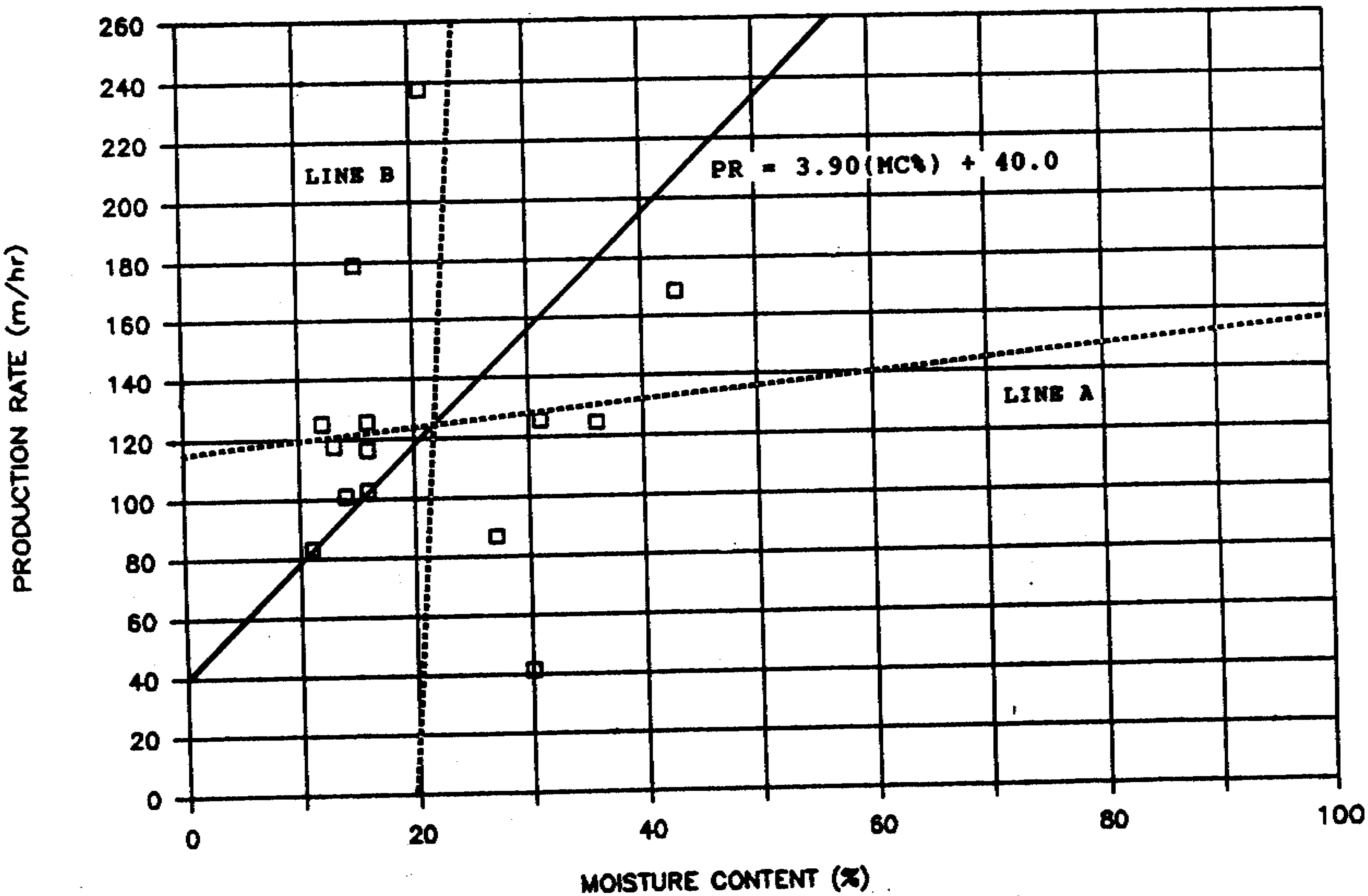


FIGURE 22 DITCH PRODUCTION vs MOISTURE CONTENT (SAND)

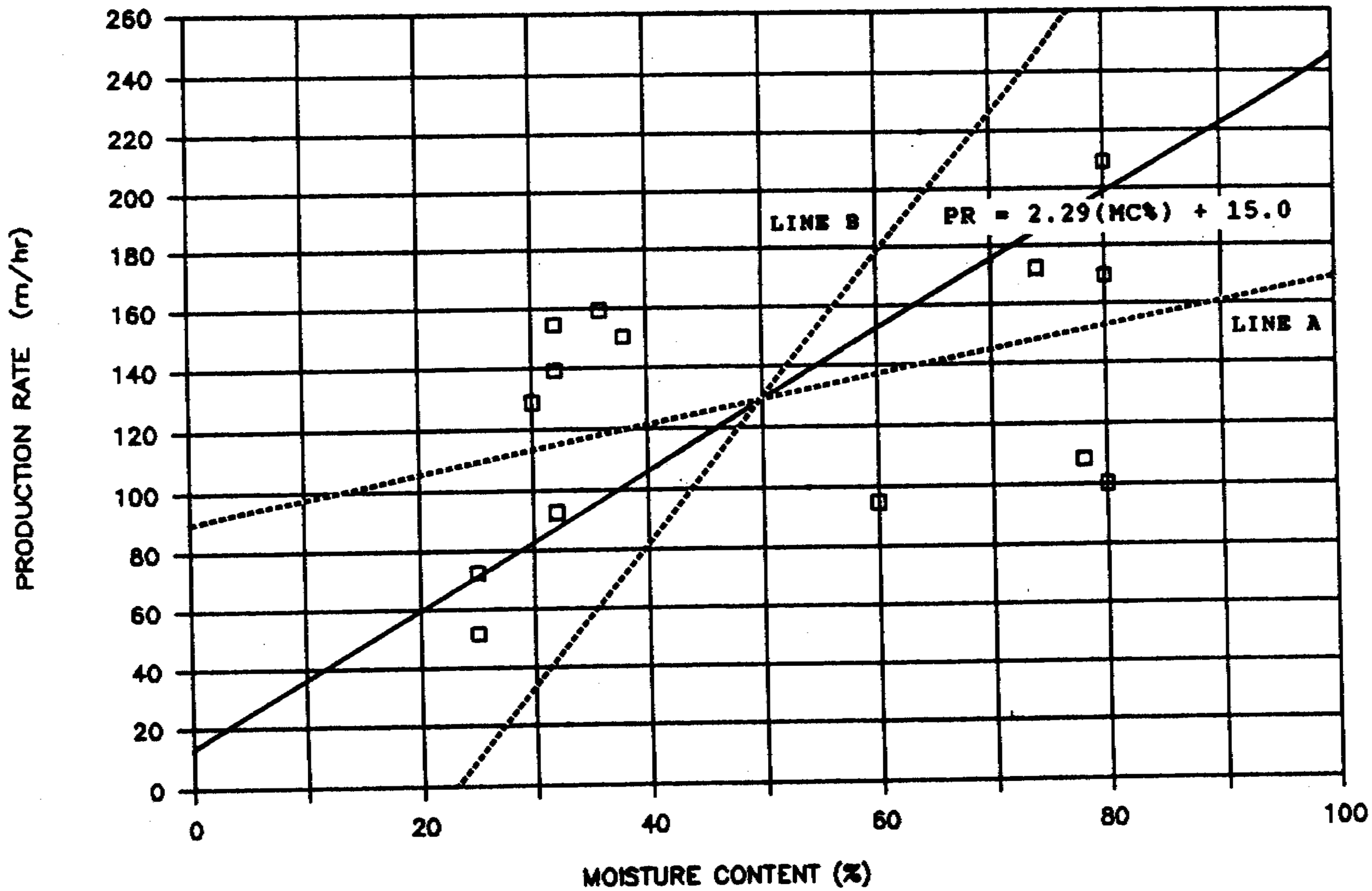


FIGURE 23 DITCH PRODUCTION vs MOISTURE CONTENT (SILT)

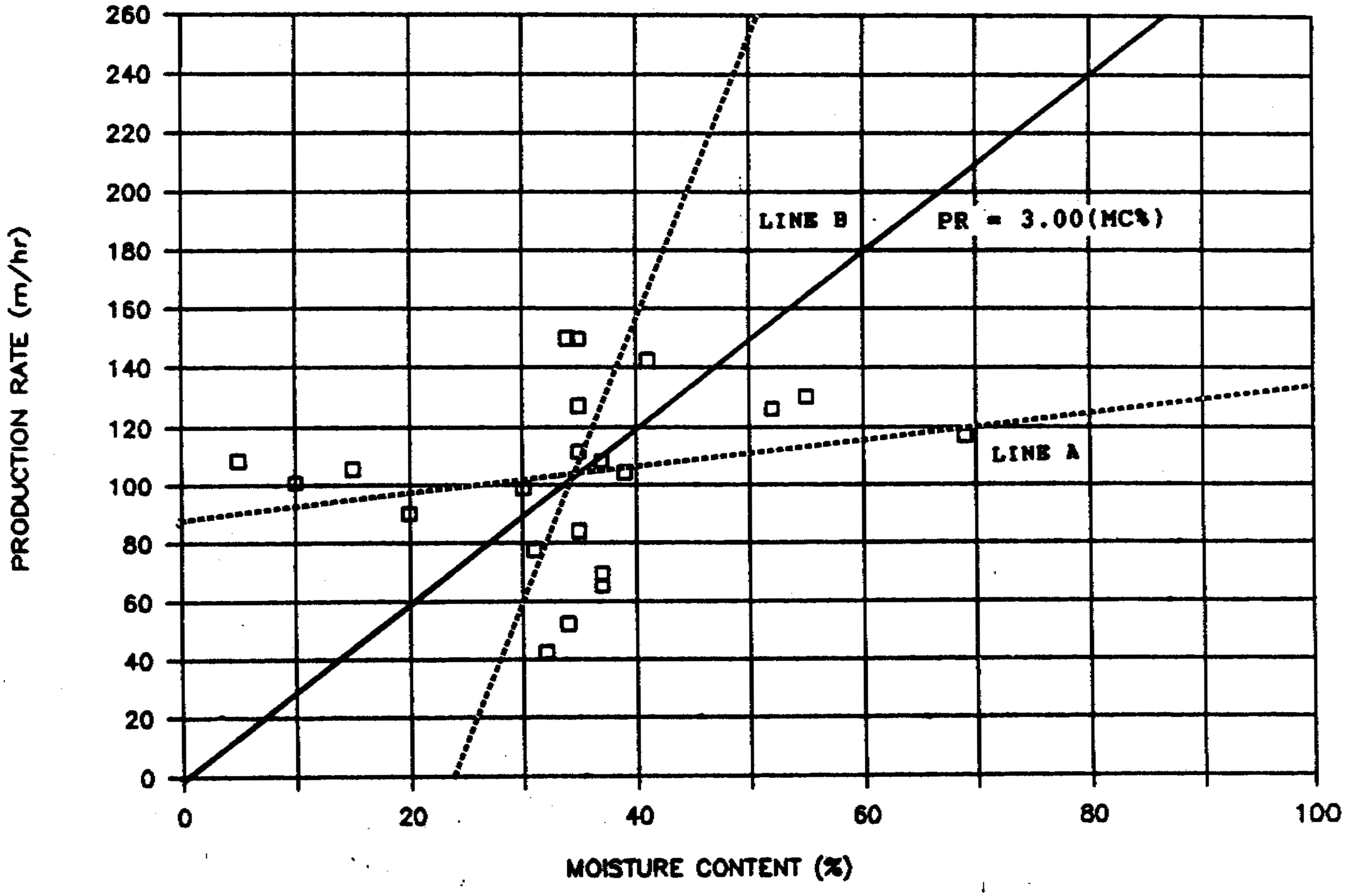


FIGURE 24 DITCH PRODUCTION vs MOISTURE CONTENT (CLAY)

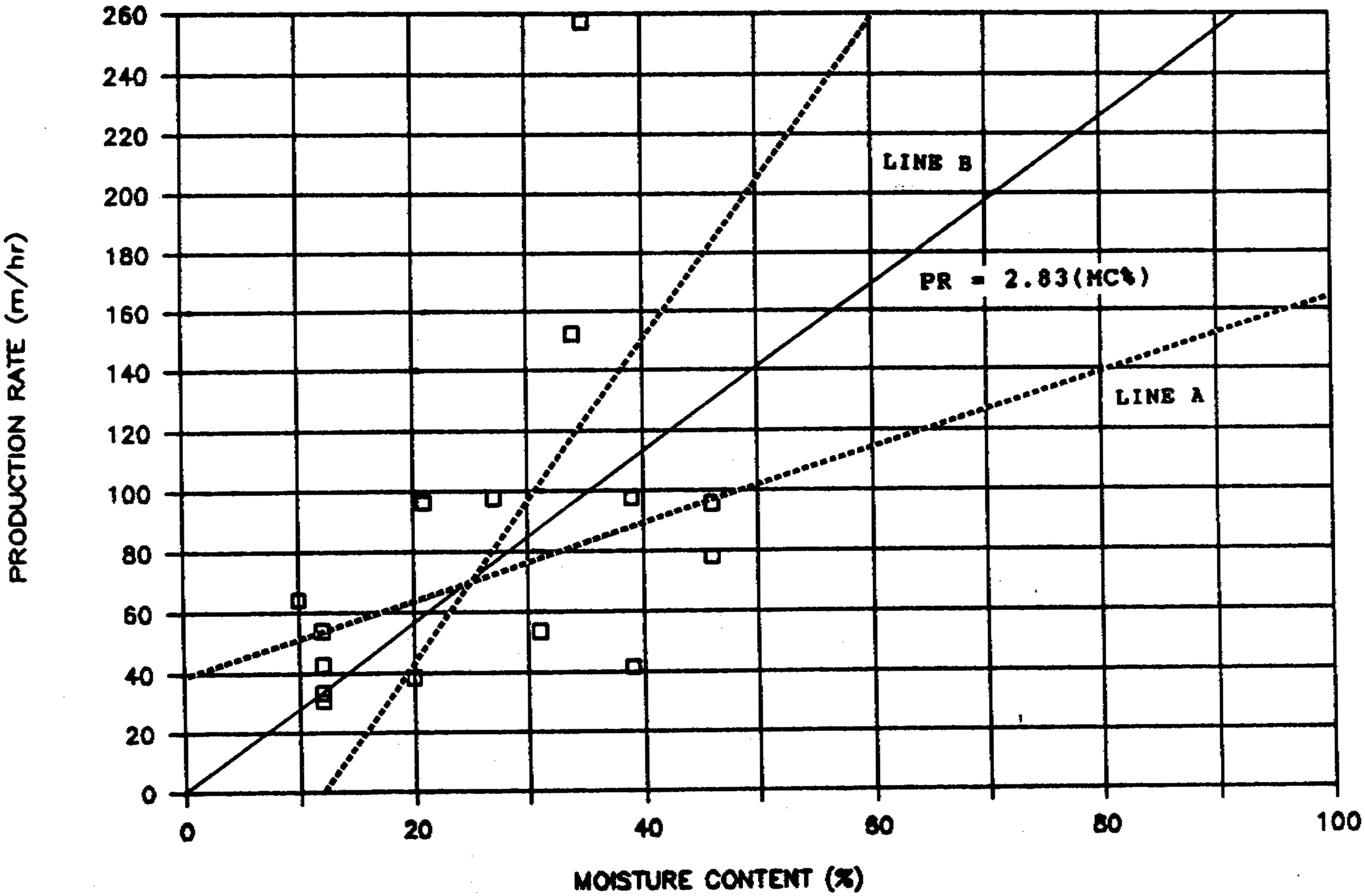


FIGURE 25 DITCH PRODUCTION vs MOISTURE CONTENT (TILL)

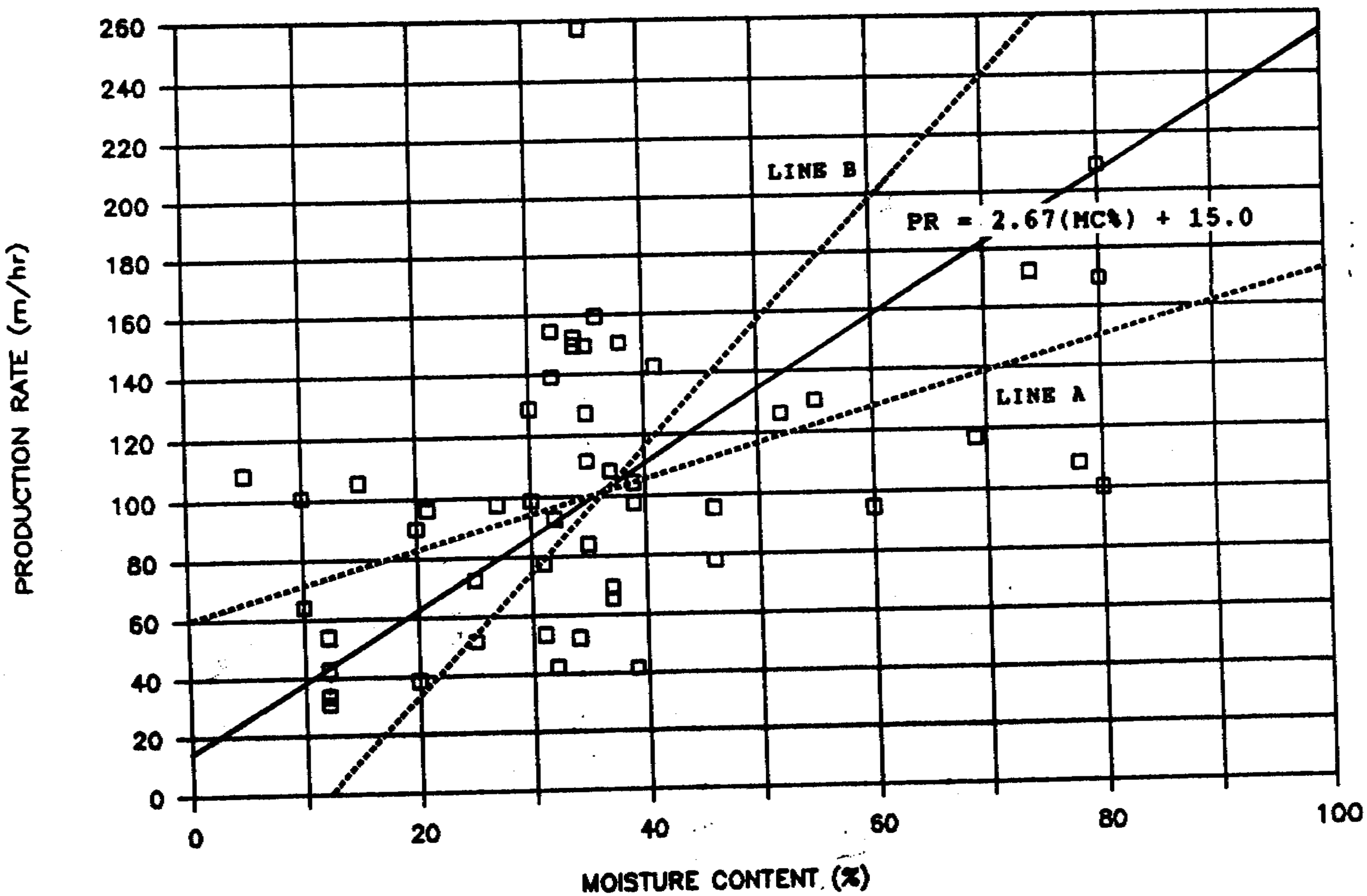


FIGURE 26 DITCH PRODUCTION vs MOISTURE CONTENT (FINE-GRAINED)

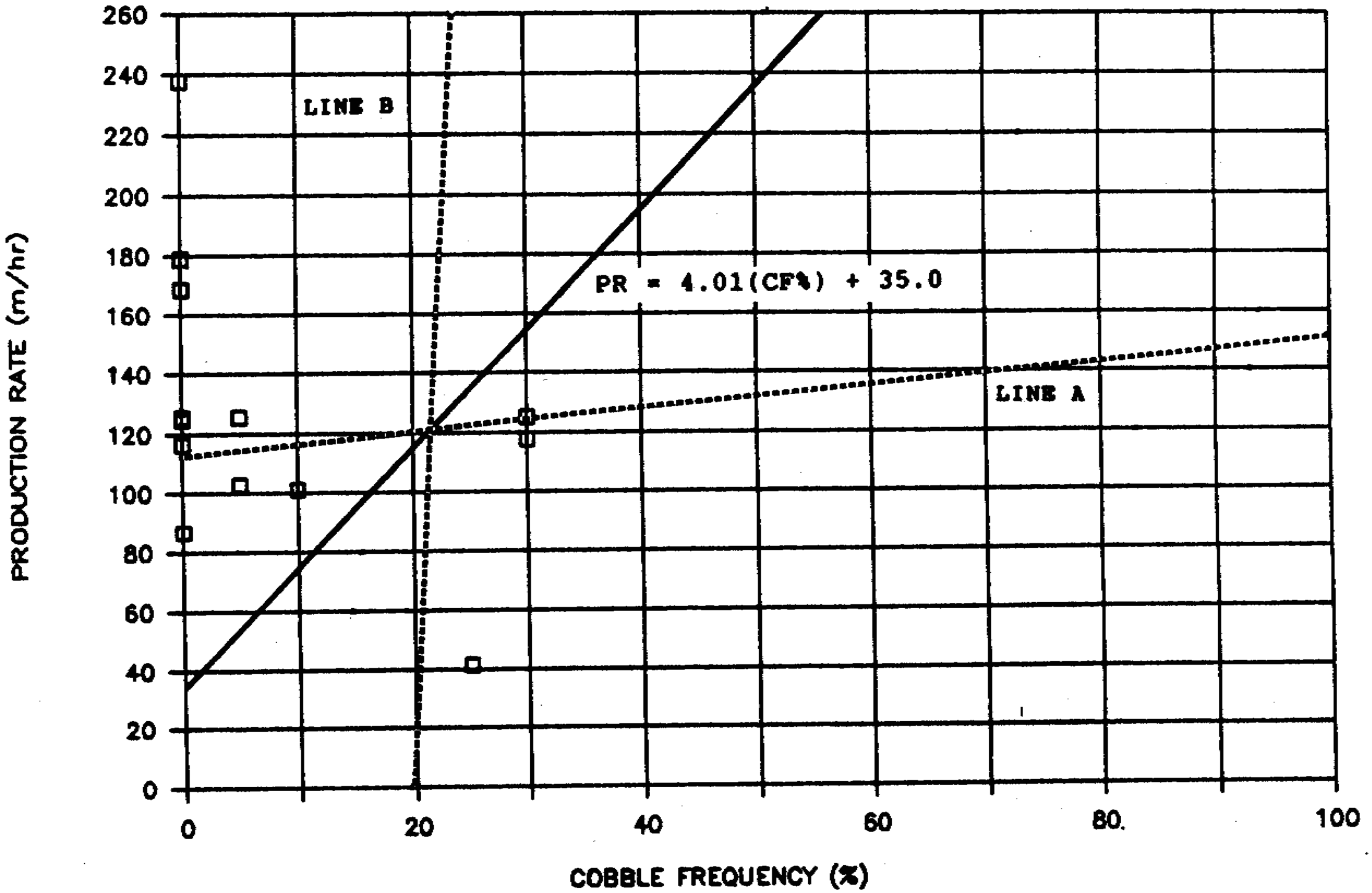


FIGURE 27 DITCH PRODUCTION vs COBBLE FREQUENCY (SAND)

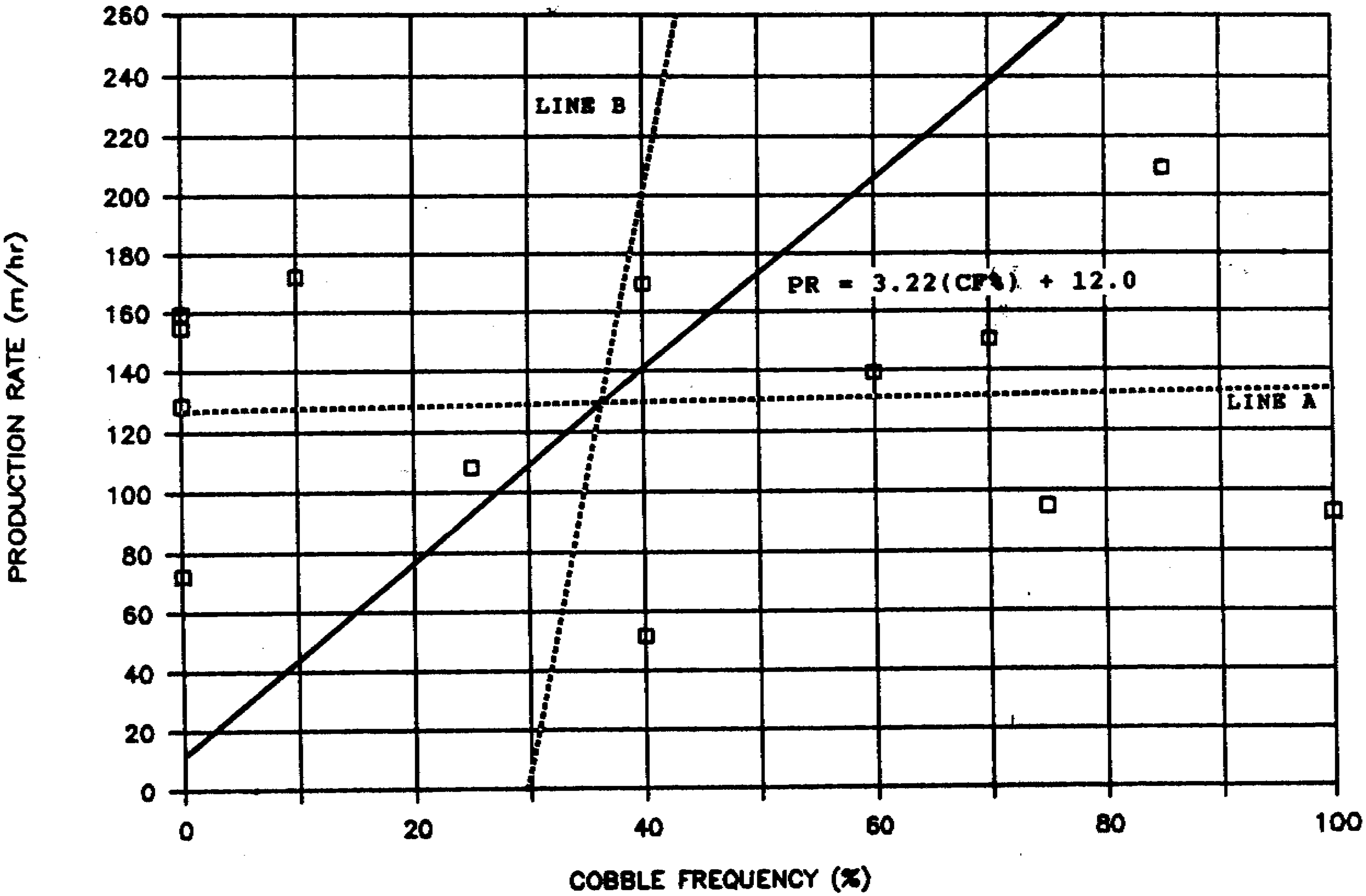


FIGURE 28 DITCH PRODUCTION vs COBBLE FREQUENCY (SILT)

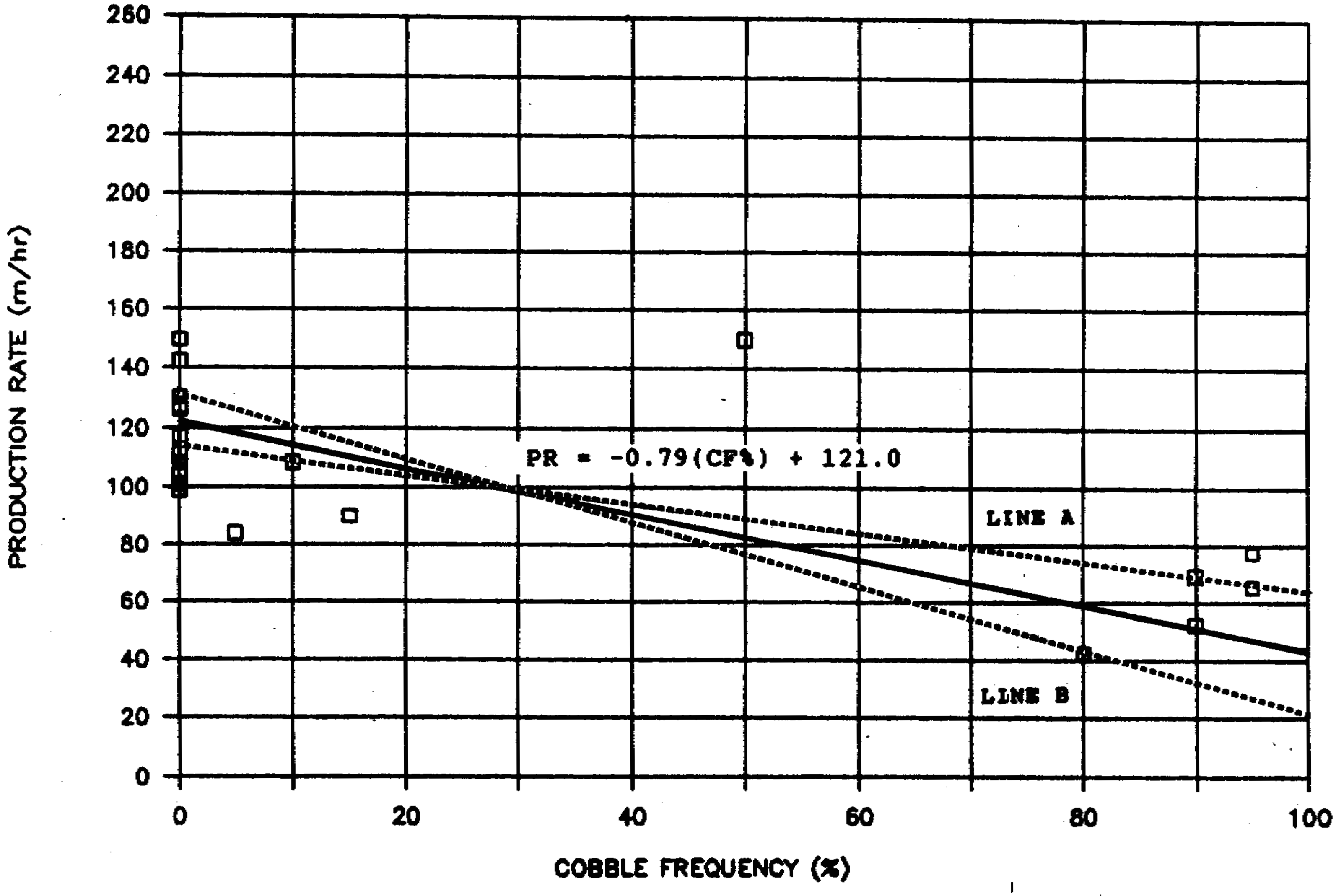


FIGURE 29 DITCH PRODUCTION vs COBBLE FREQUENCY (CLAY)

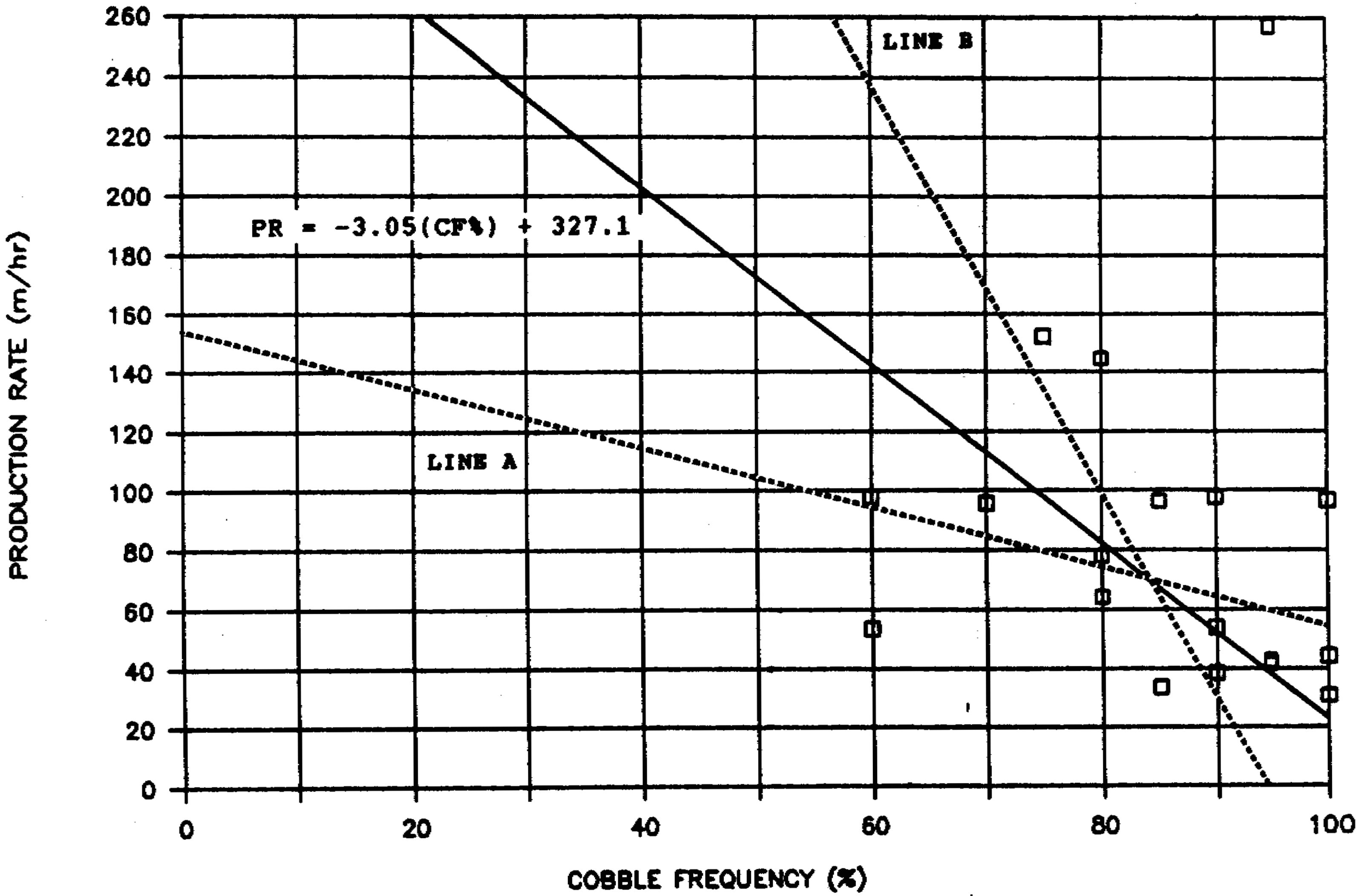


FIGURE 30 DITCH PRODUCTION vs COBBLE FREQUENCY (TILL)

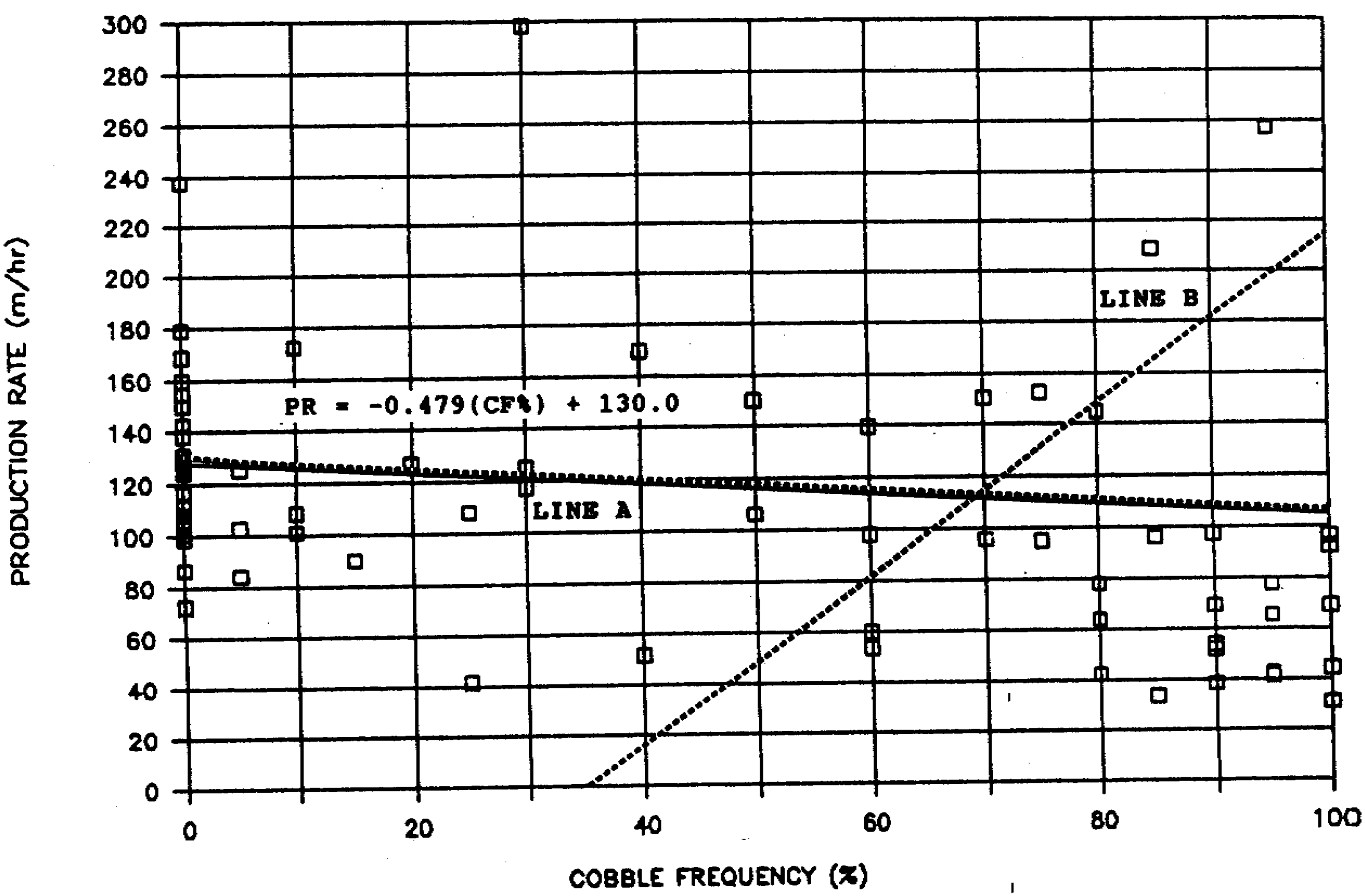


FIGURE 31 DITCH PRODUCTION vs COBBLE FREQUENCY (ALL)

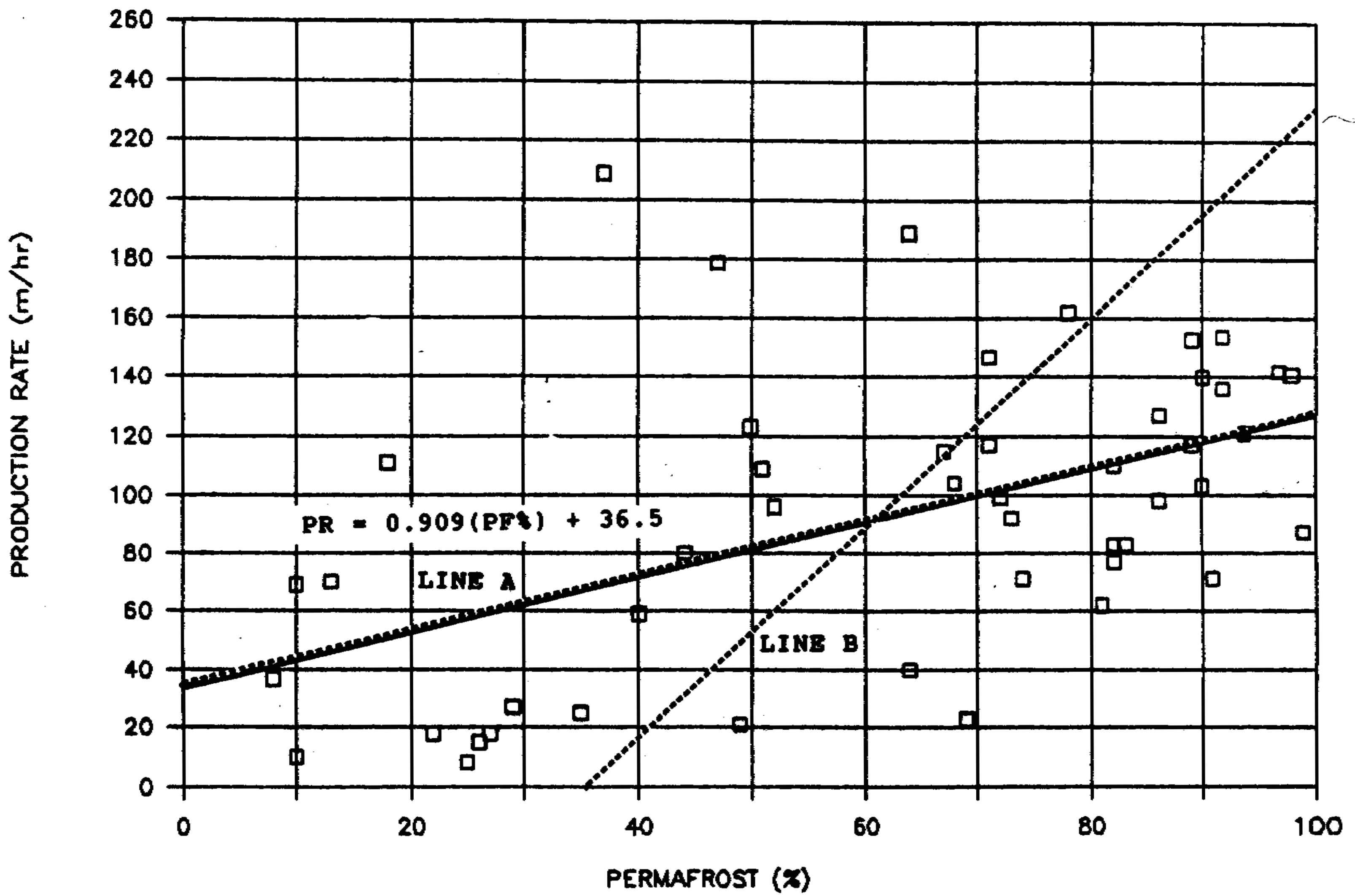


FIGURE 32 DITCH PRODUCTION vs PERMAFROST DISTRIBUTION

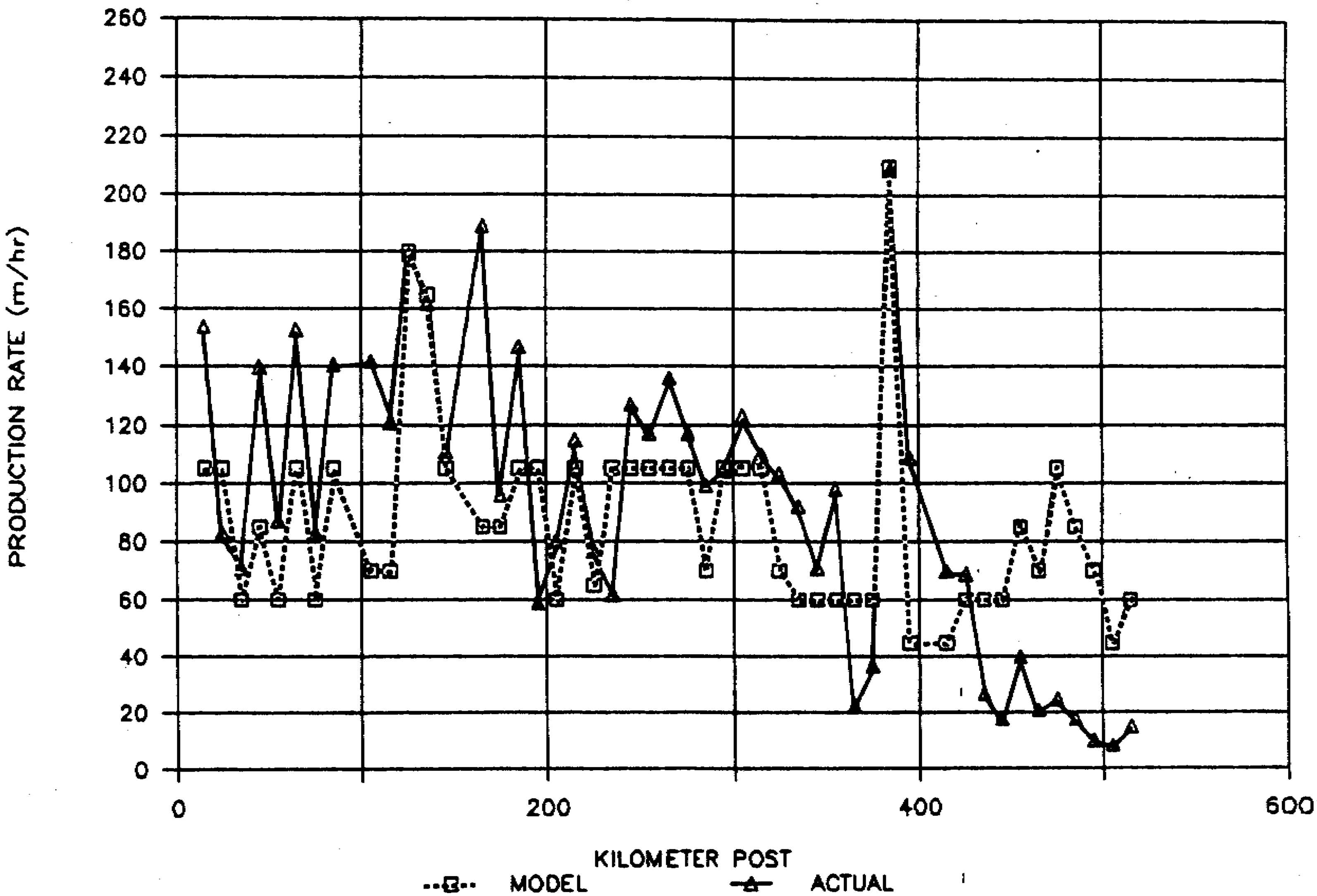


FIGURE 33 MODEL I - TERRAIN TYPE

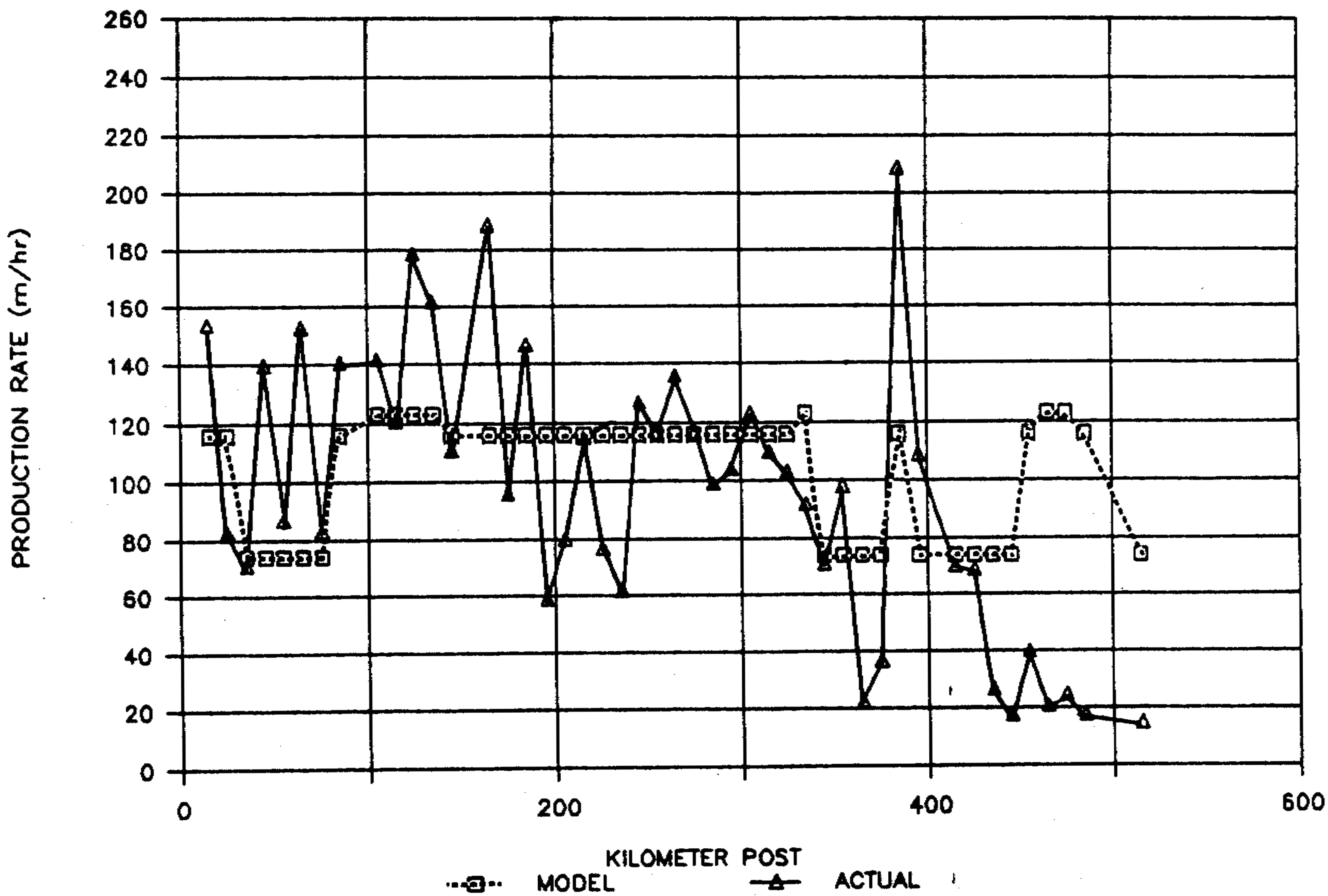


FIGURE 34 MODEL II - SOIL TYPE

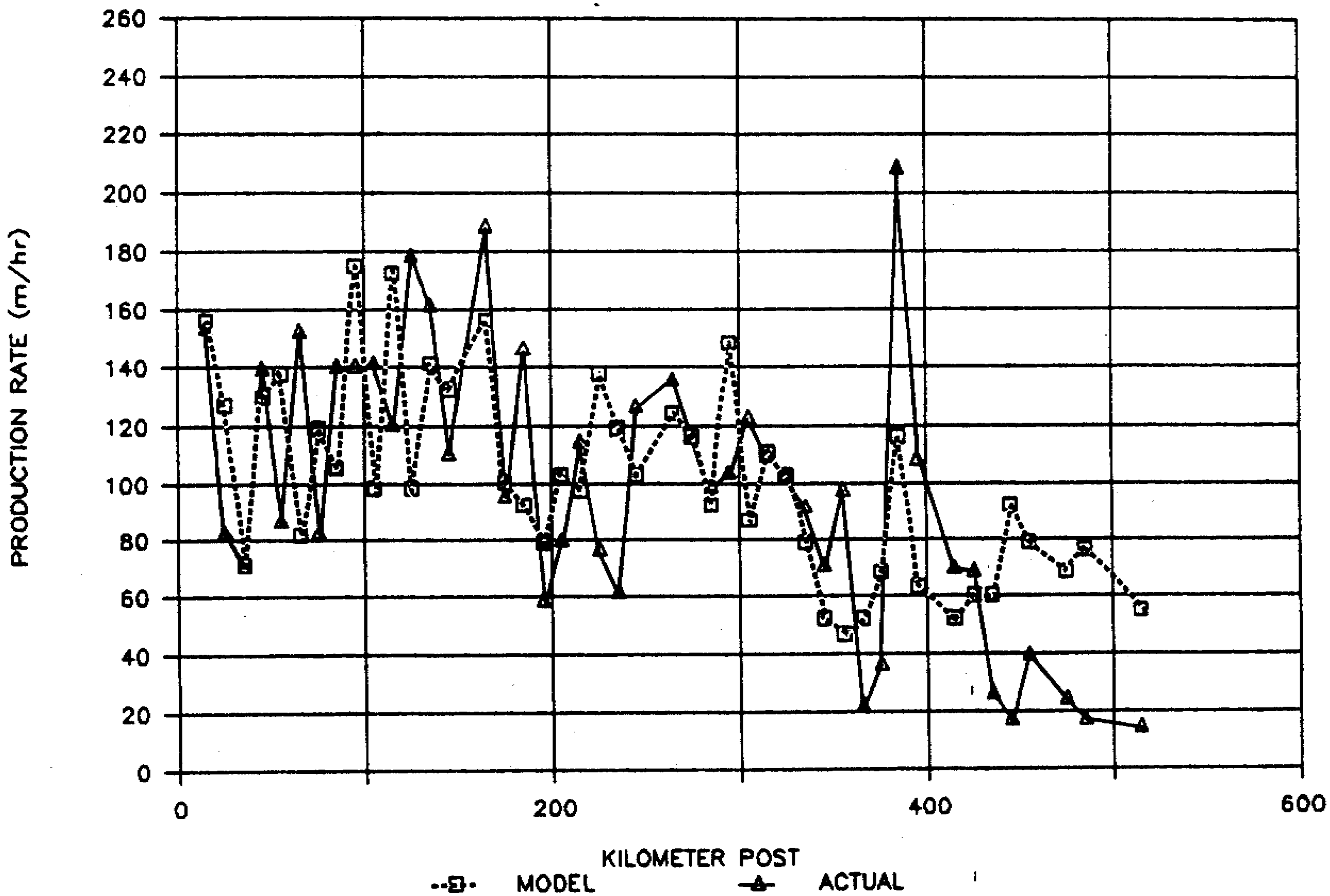


FIGURE 35 MODEL III - MOISTURE CONTENT

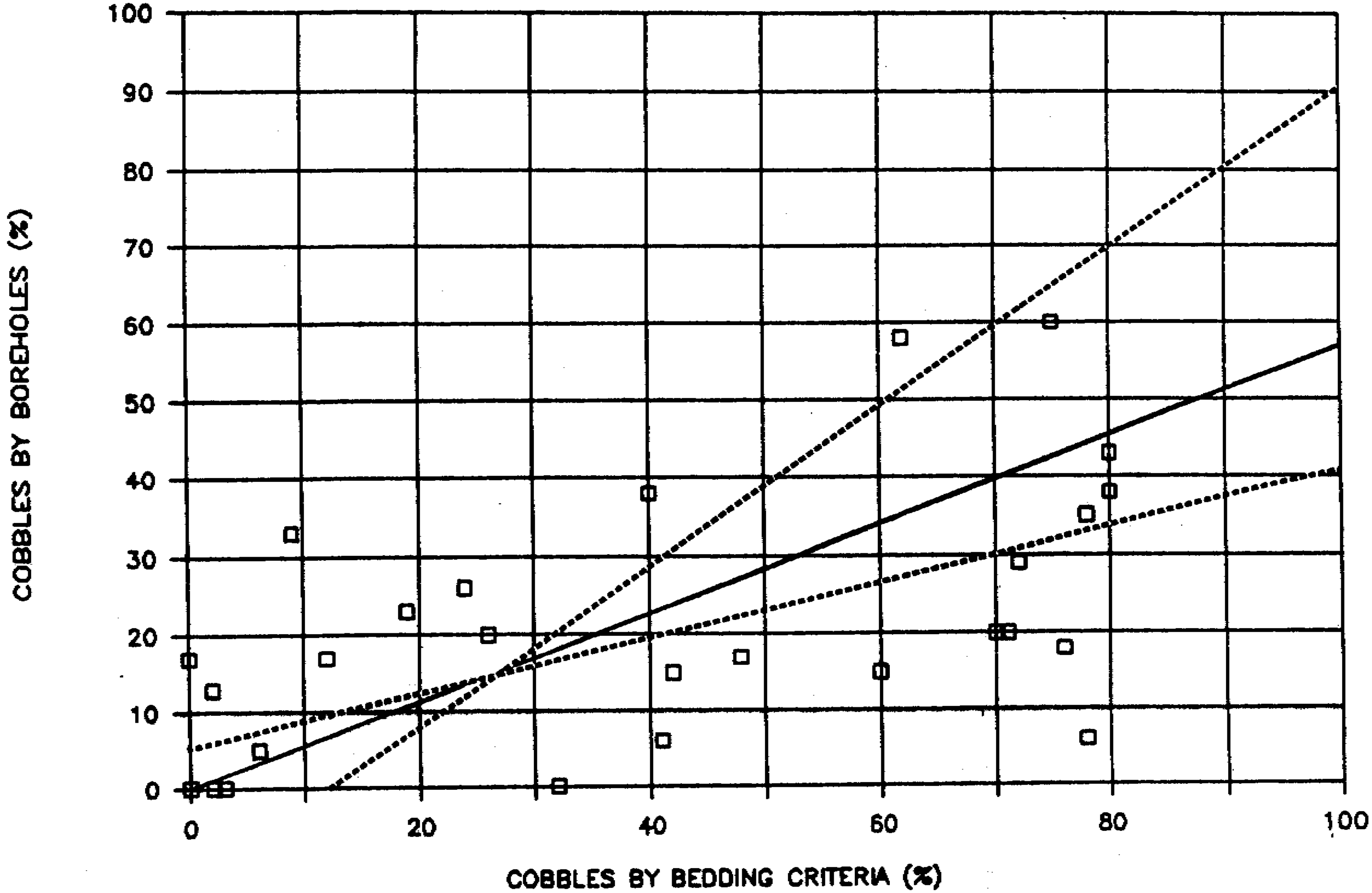


FIGURE 36 COBBLE FREQUENCY CORRELATION BETWEEN BEDDING CRITERIA AND BOREHOLE OCCURRENCE

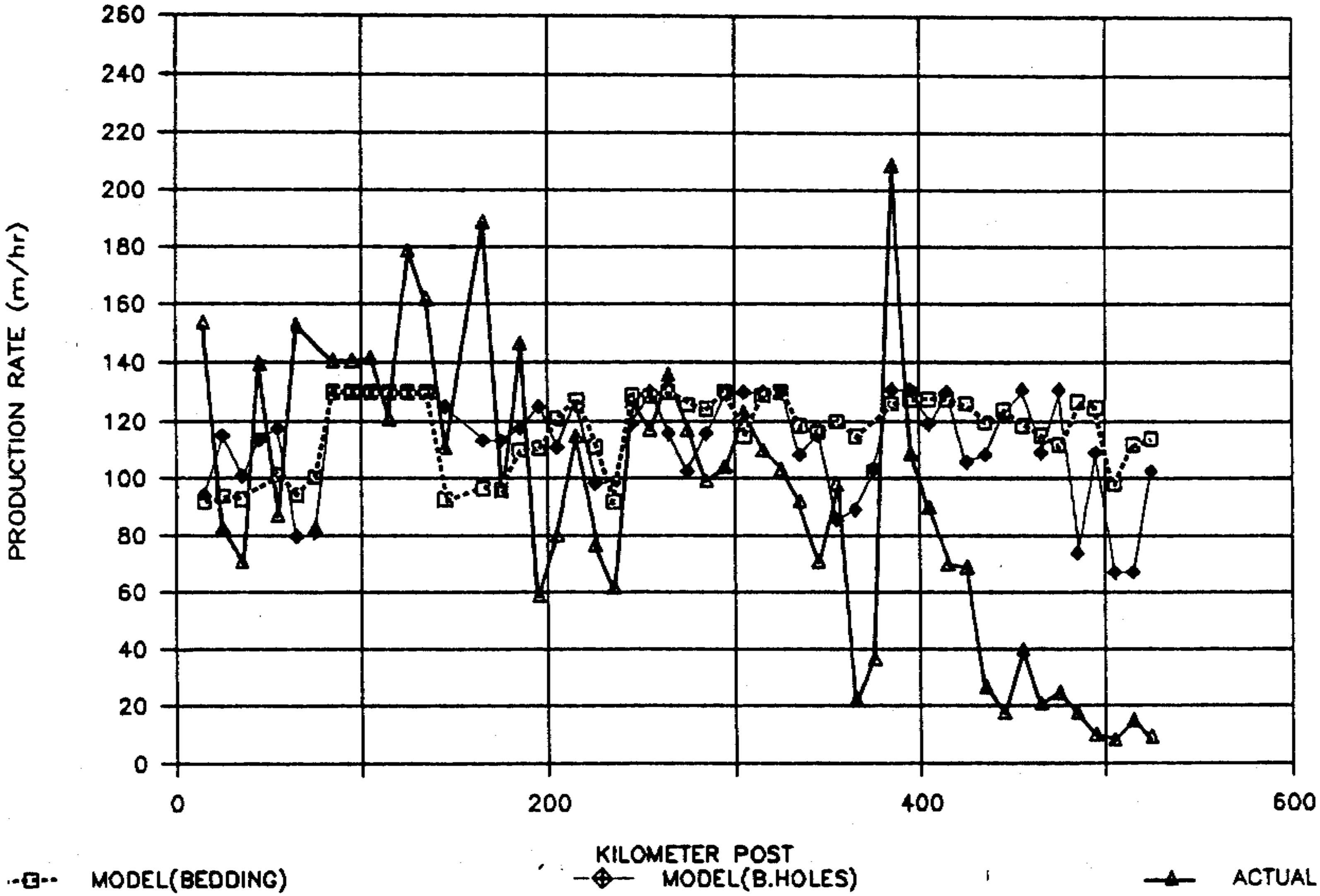


FIGURE 37 MODEL IV - COBBLE FREQUENCY

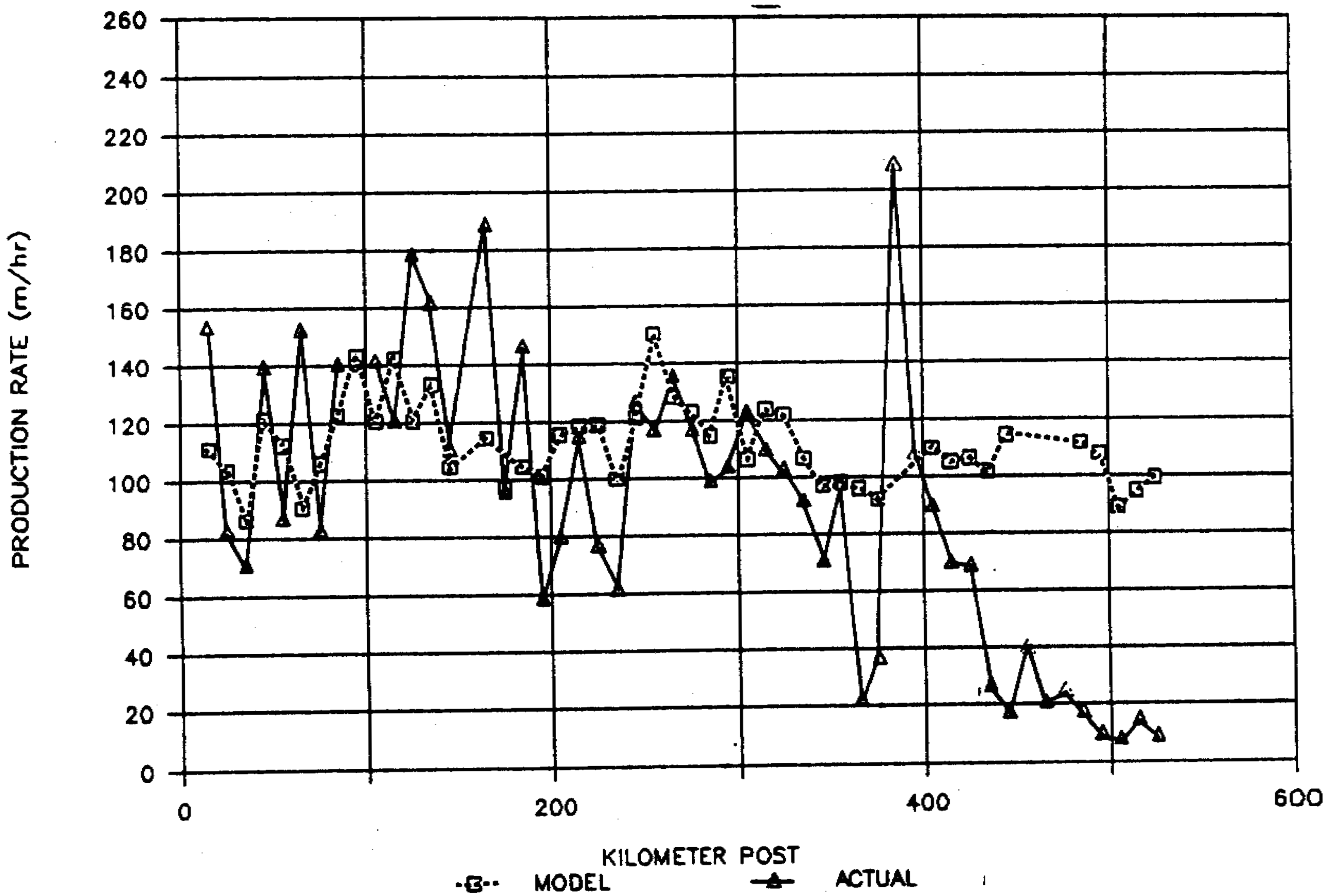


FIGURE 38 MODEL V (Case A) - COBBLE FREQUENCY (70%)/MOISTURE CONTENT (30%)

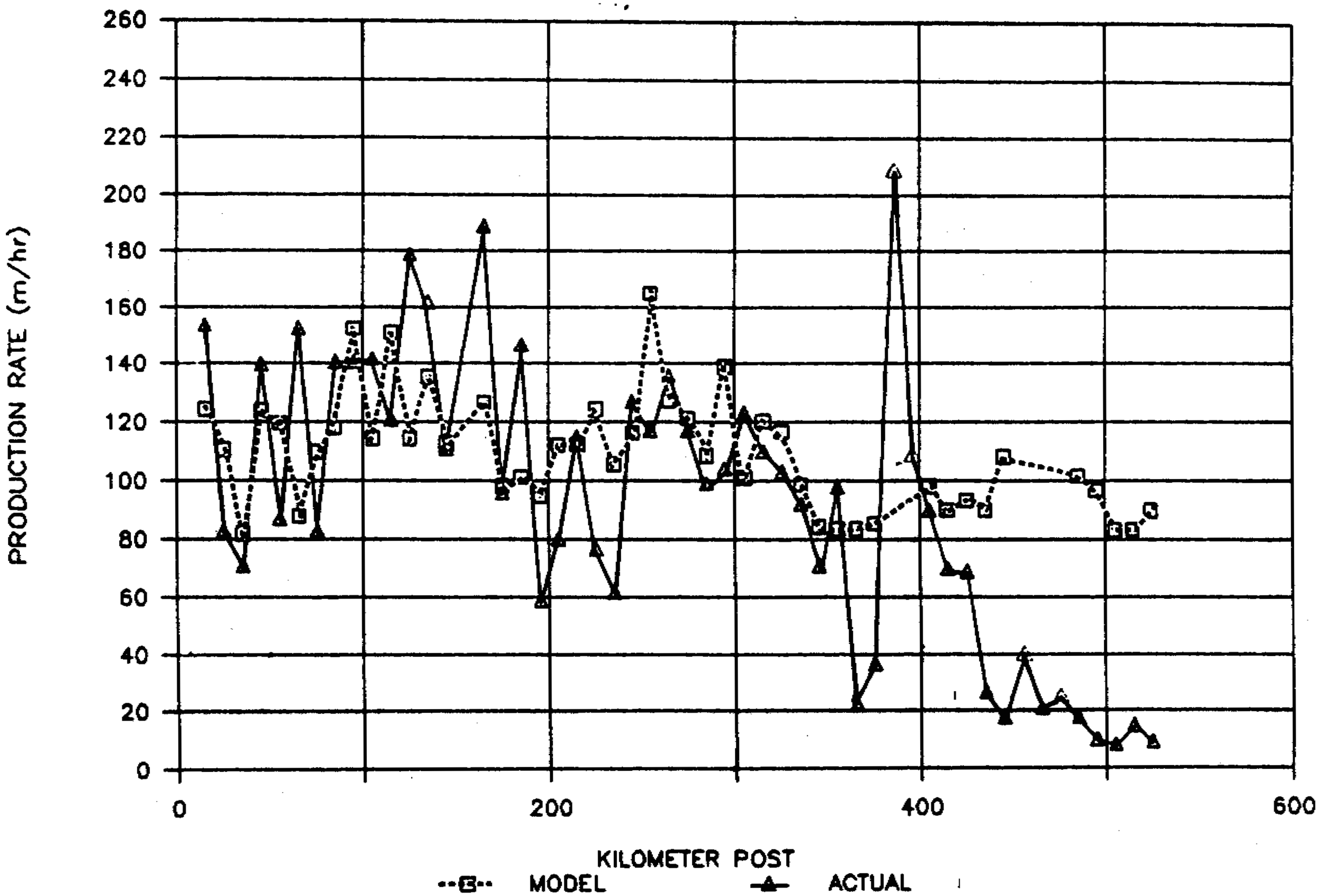


FIGURE 39   MODEL V (Case B) - COBBLE FREQUENCY (50%)/MOISTURE CONTENT (50%)

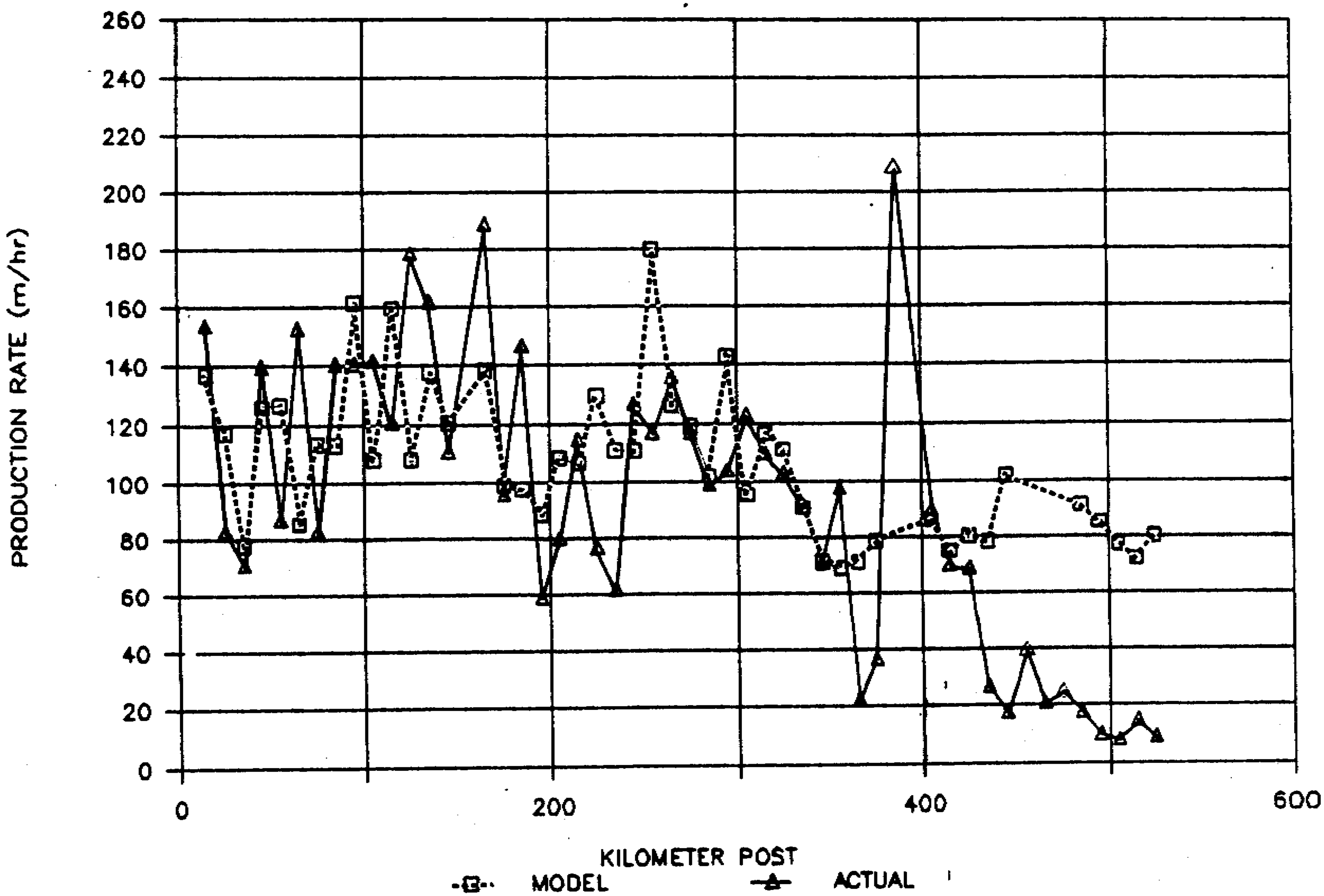


FIGURE 40 MODEL V (Case C) - COBBLE FREQUENCY (30%)/MOISTURE CONTENT (70%)

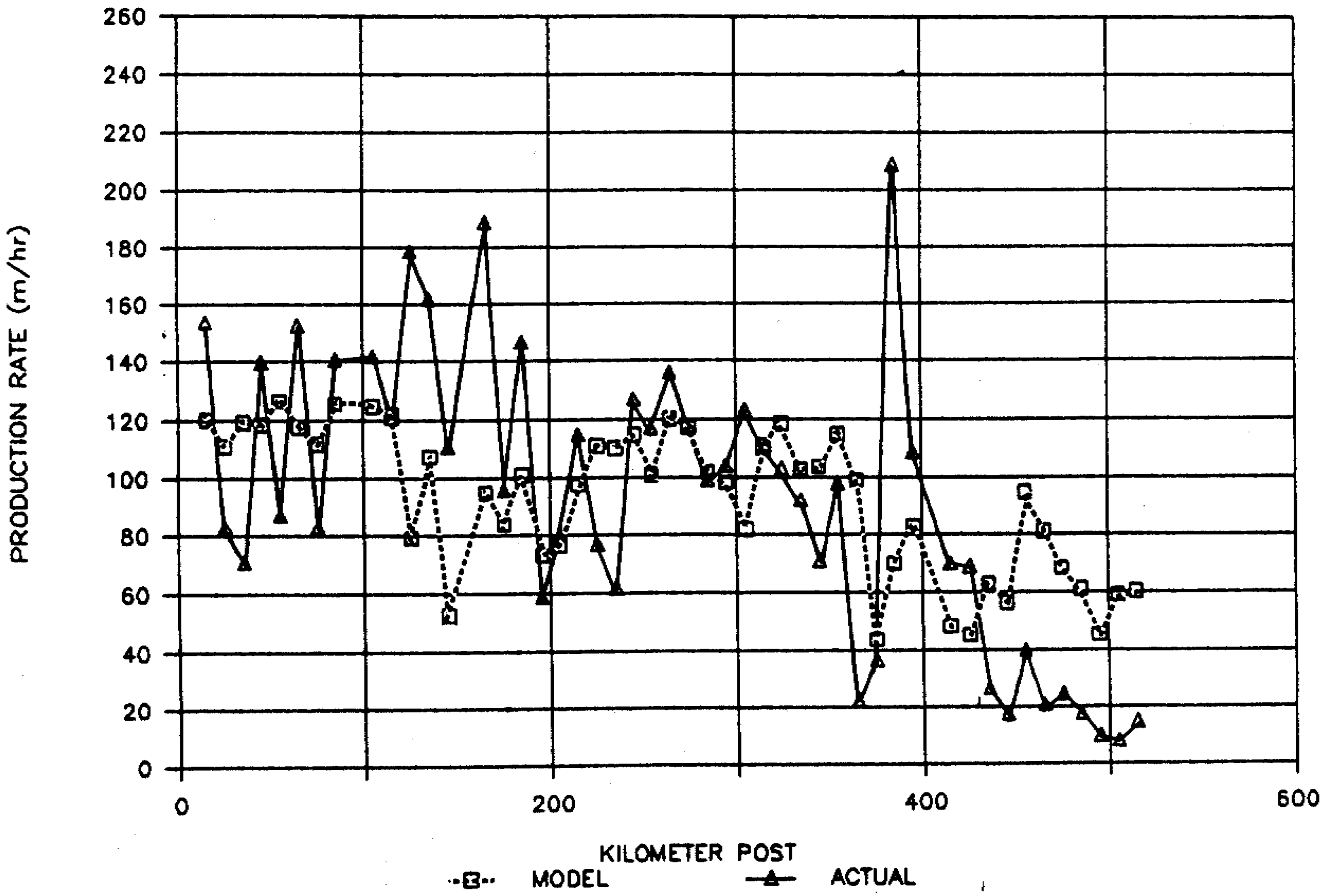
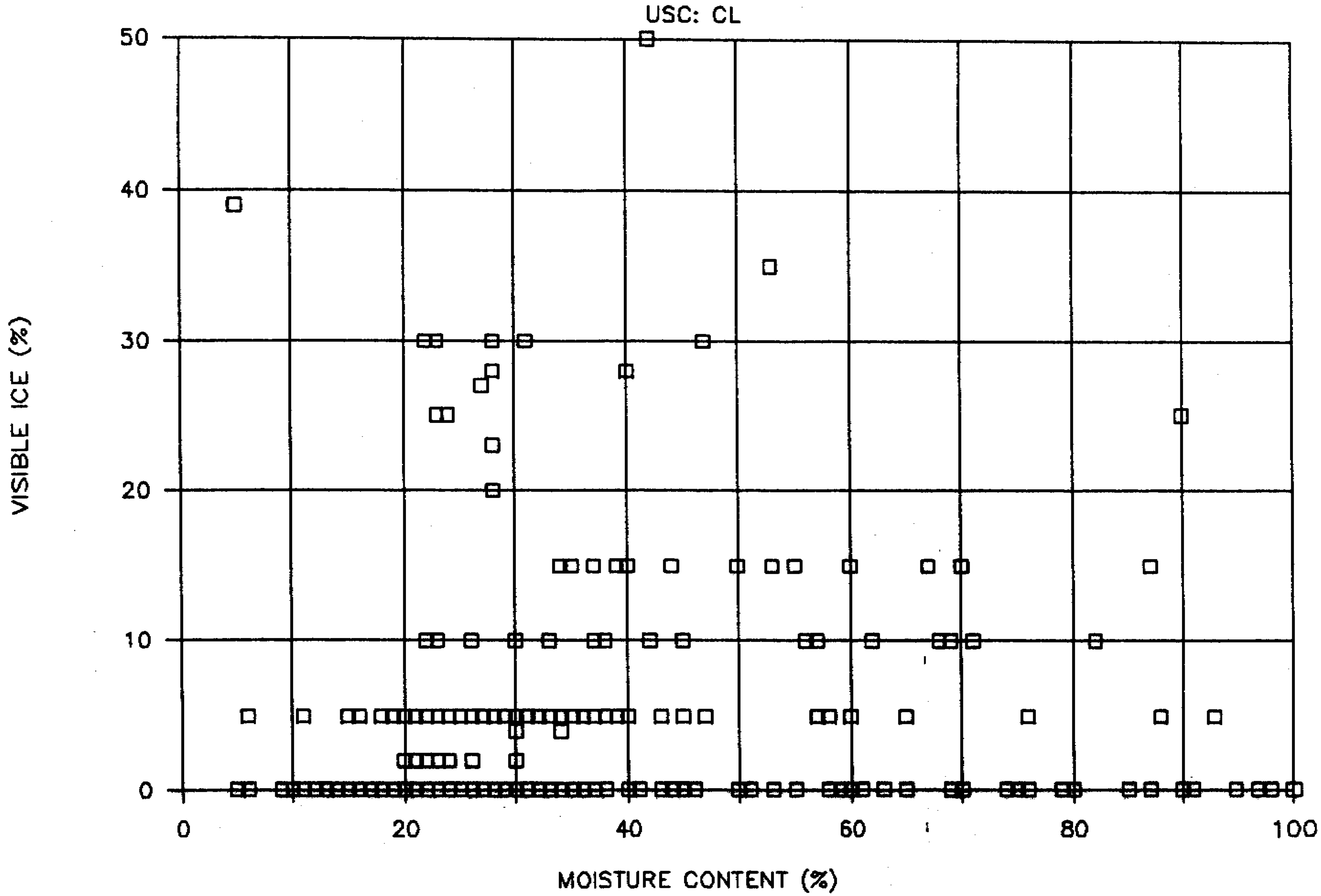
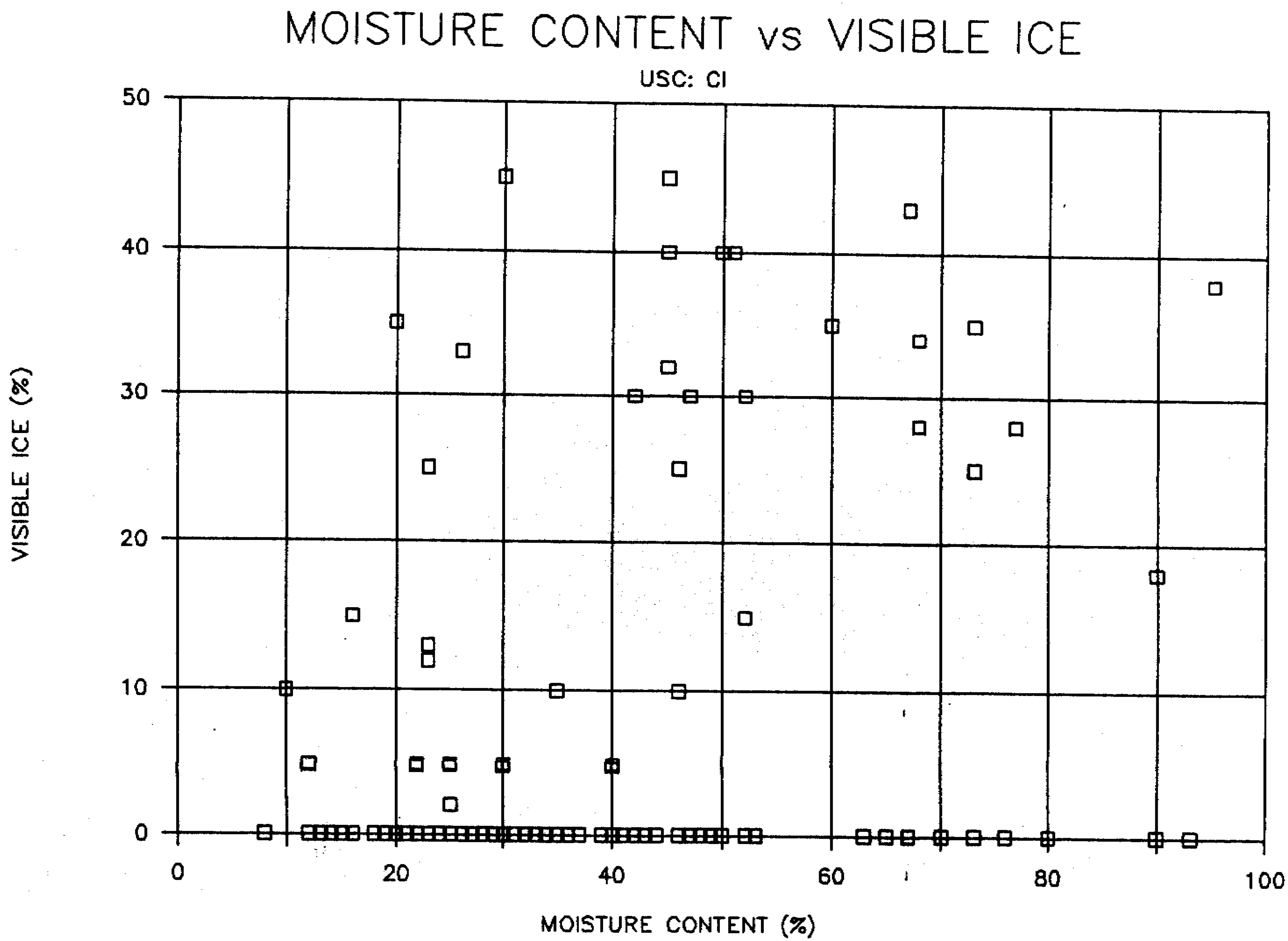


FIGURE 41 MODEL VI - PERMAFROST

APPENDIX B
MOISTURE CONTENT/ VISIBLE ICE RELATIONSHIP

MOISTURE CONTENT vs VISIBLE ICE

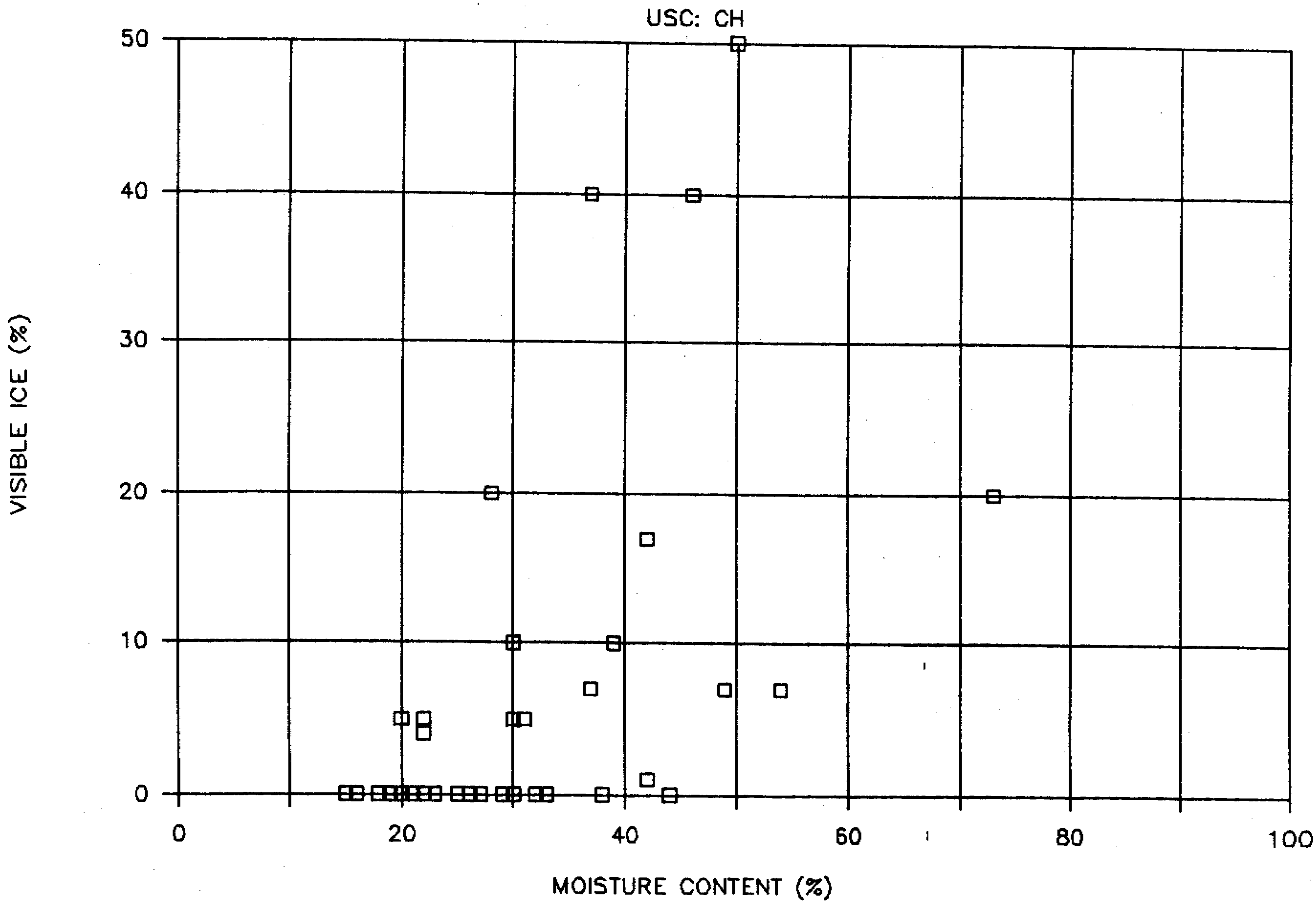


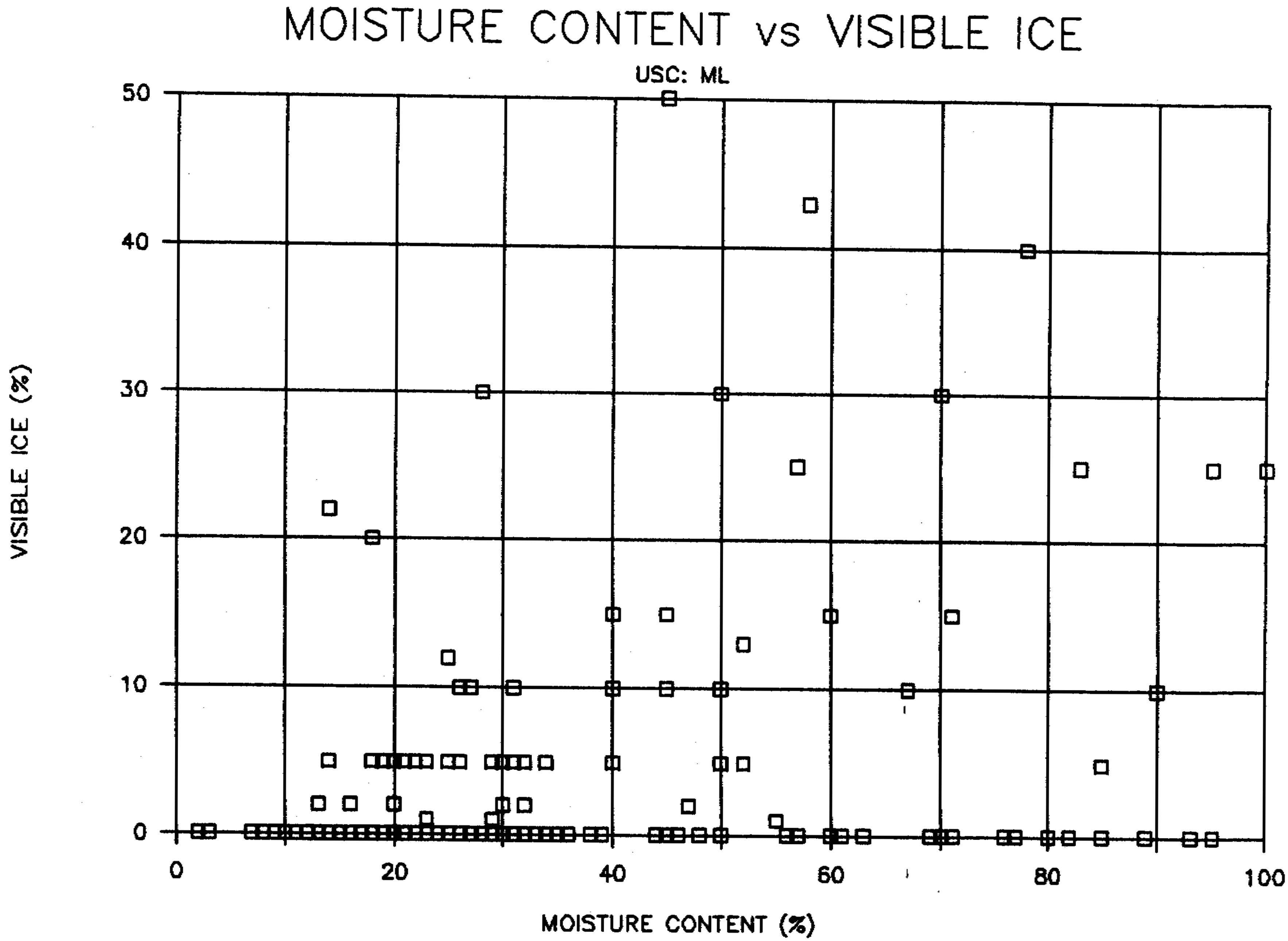


MOISTURE CONTENT vs VISIBLE ICE
USC: CI
VISIBLE ICE (%)
MOISTURE CONTENT (%)
0
10
20
30
40
50
0
20
40
60
80
100

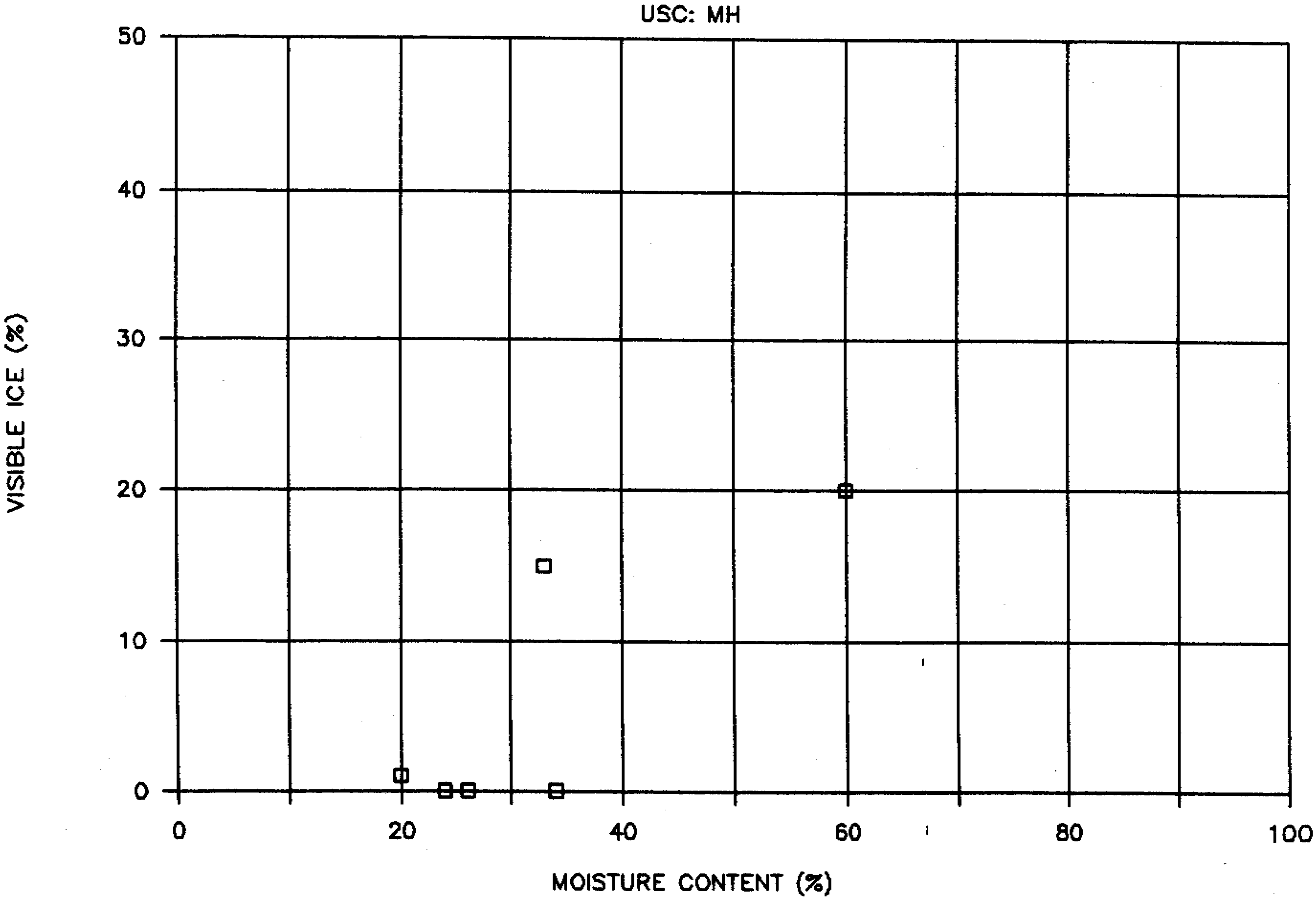
B-2

MOISTURE CONTENT vs VISIBLE ICE

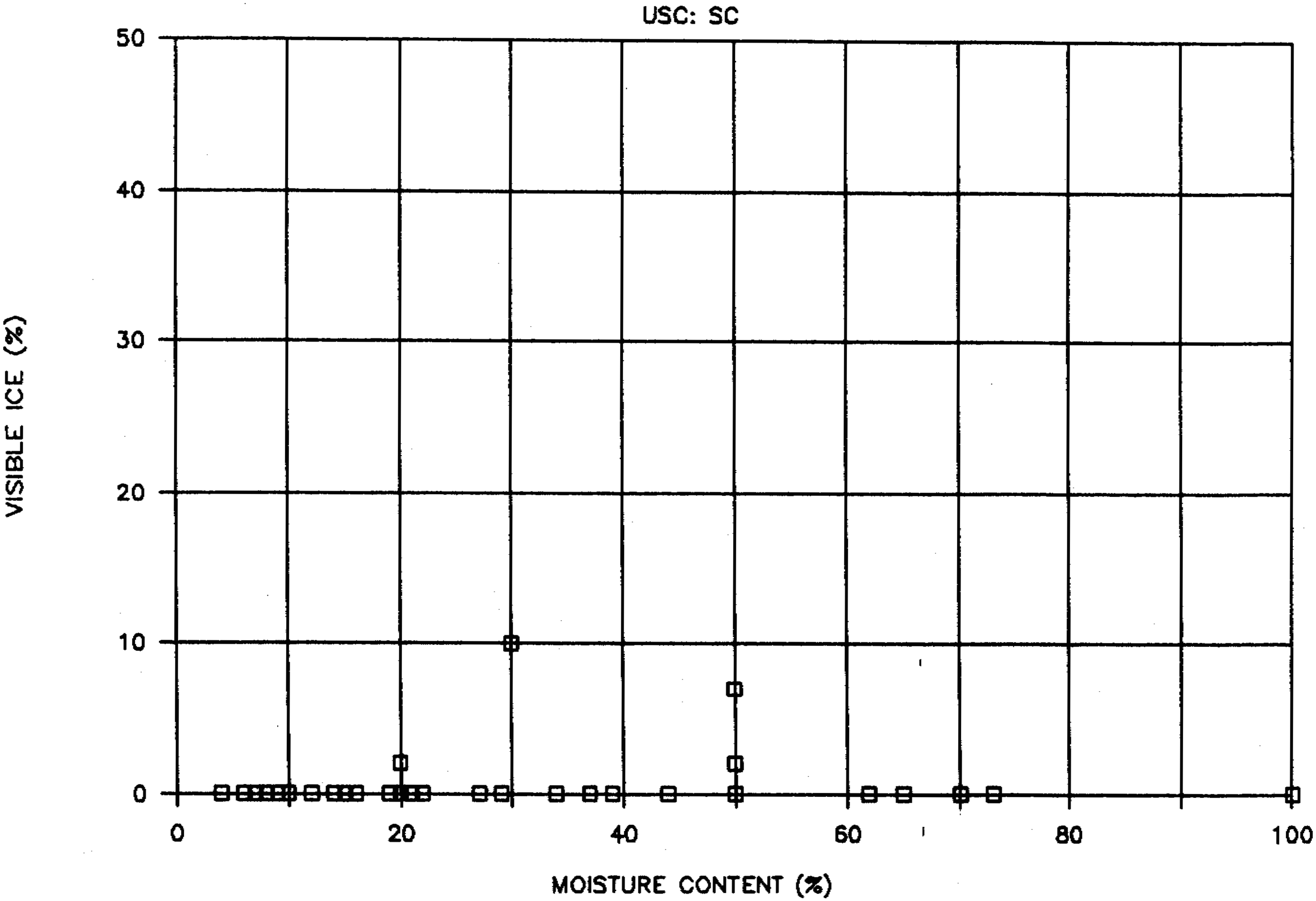



MOISTURE CONTENT vs VISIBLE ICE
USC: ML
VISIBLE ICE (%)
MOISTURE CONTENT (%)
0
10
20
30
40
50
0
20
40
60
80
100

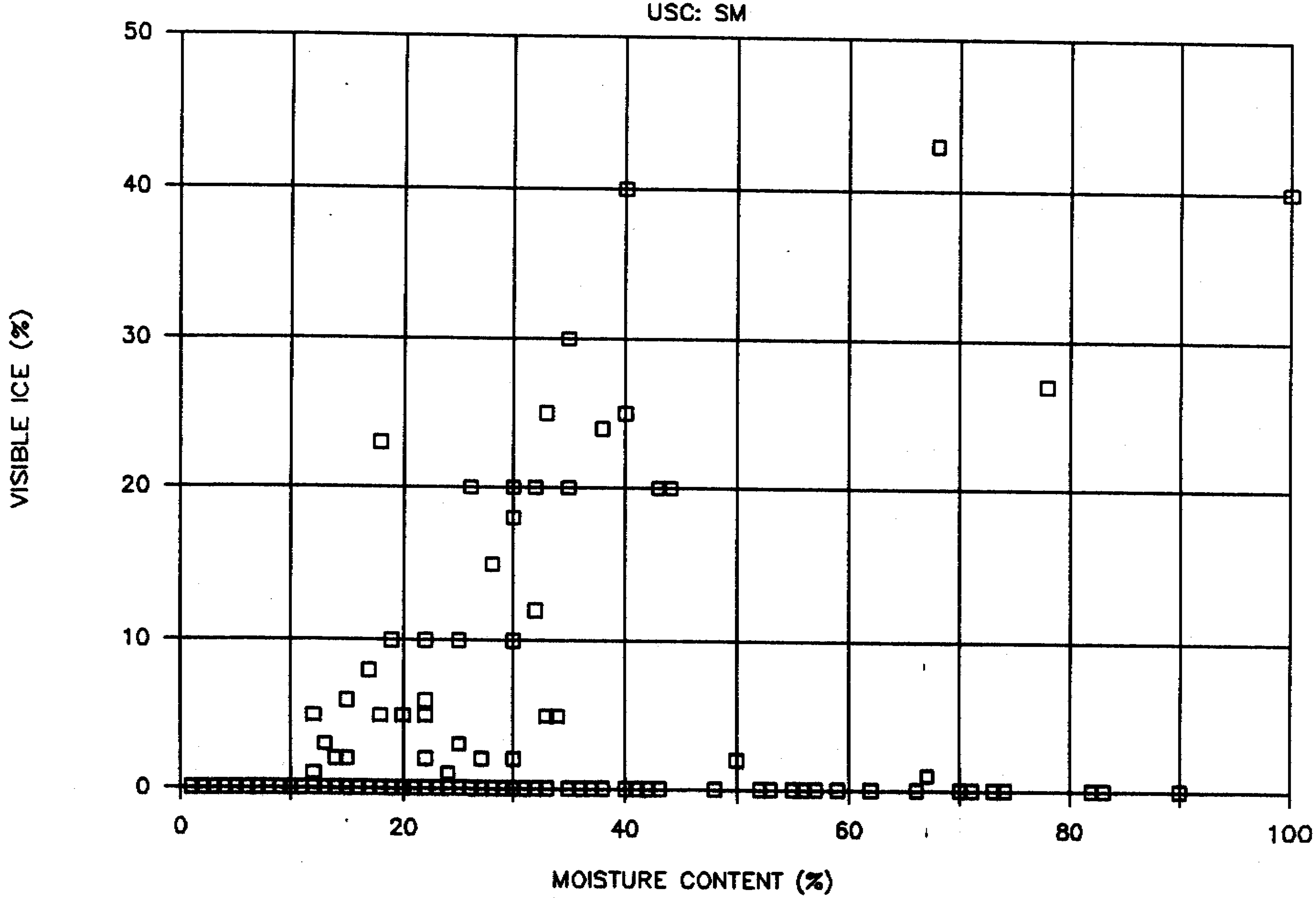
MOISTURE CONTENT vs VISIBLE ICE



MOISTURE CONTENT vs VISIBLE ICE

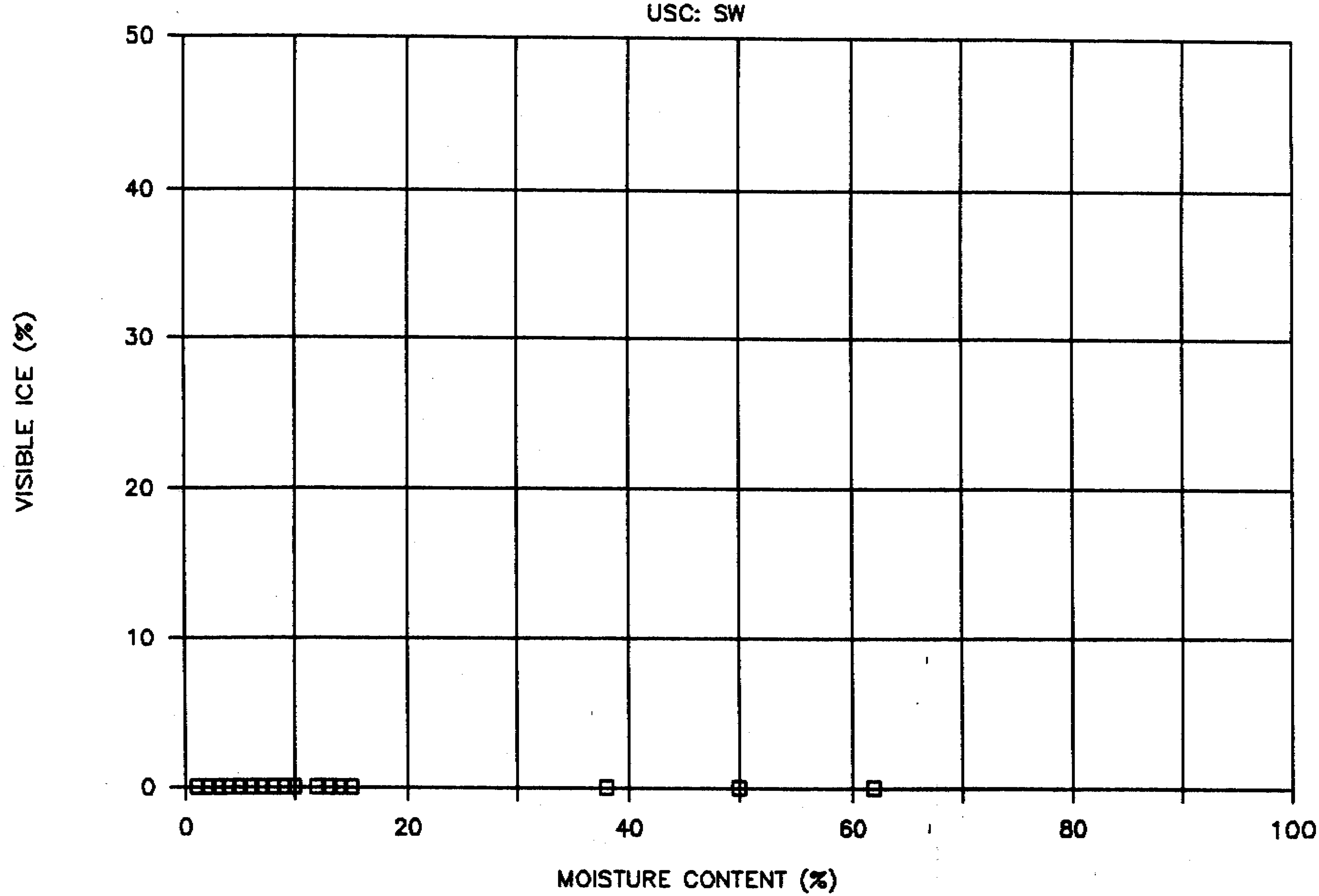


MOISTURE CONTENT vs VISIBLE ICE



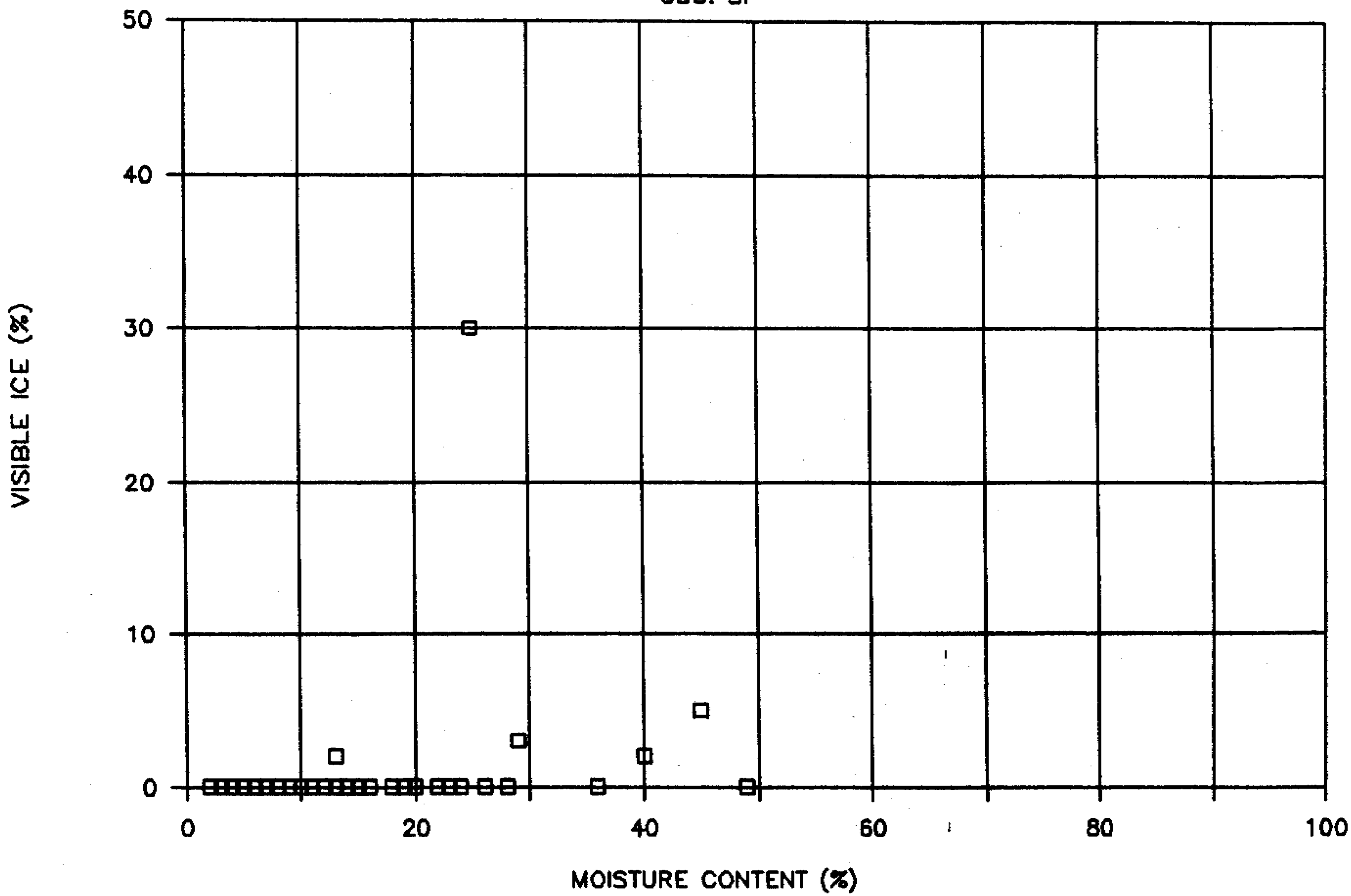
B-7

MOISTURE CONTENT vs VISIBLE ICE



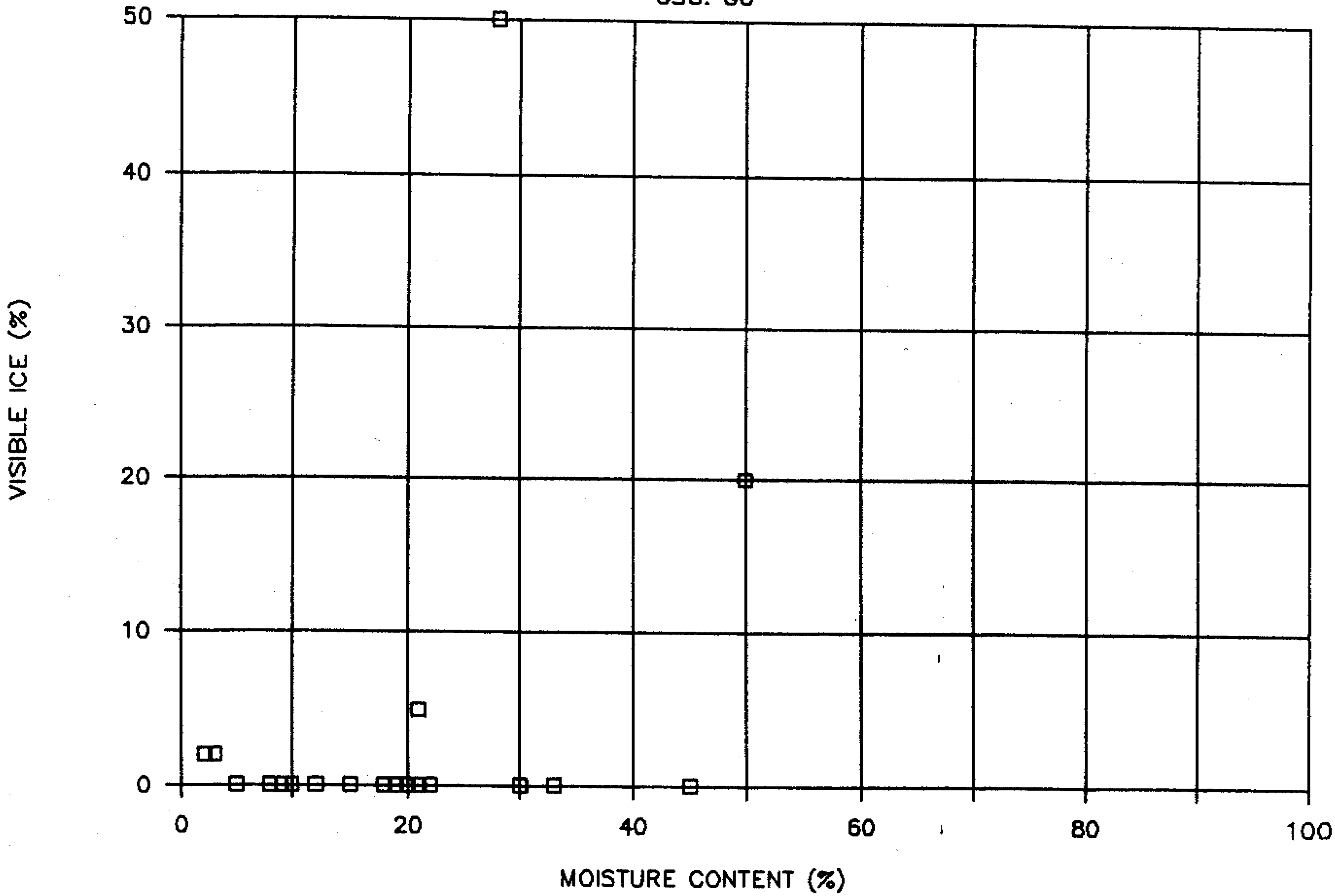
MOISTURE CONTENT vs VISIBLE ICE

USC: SP

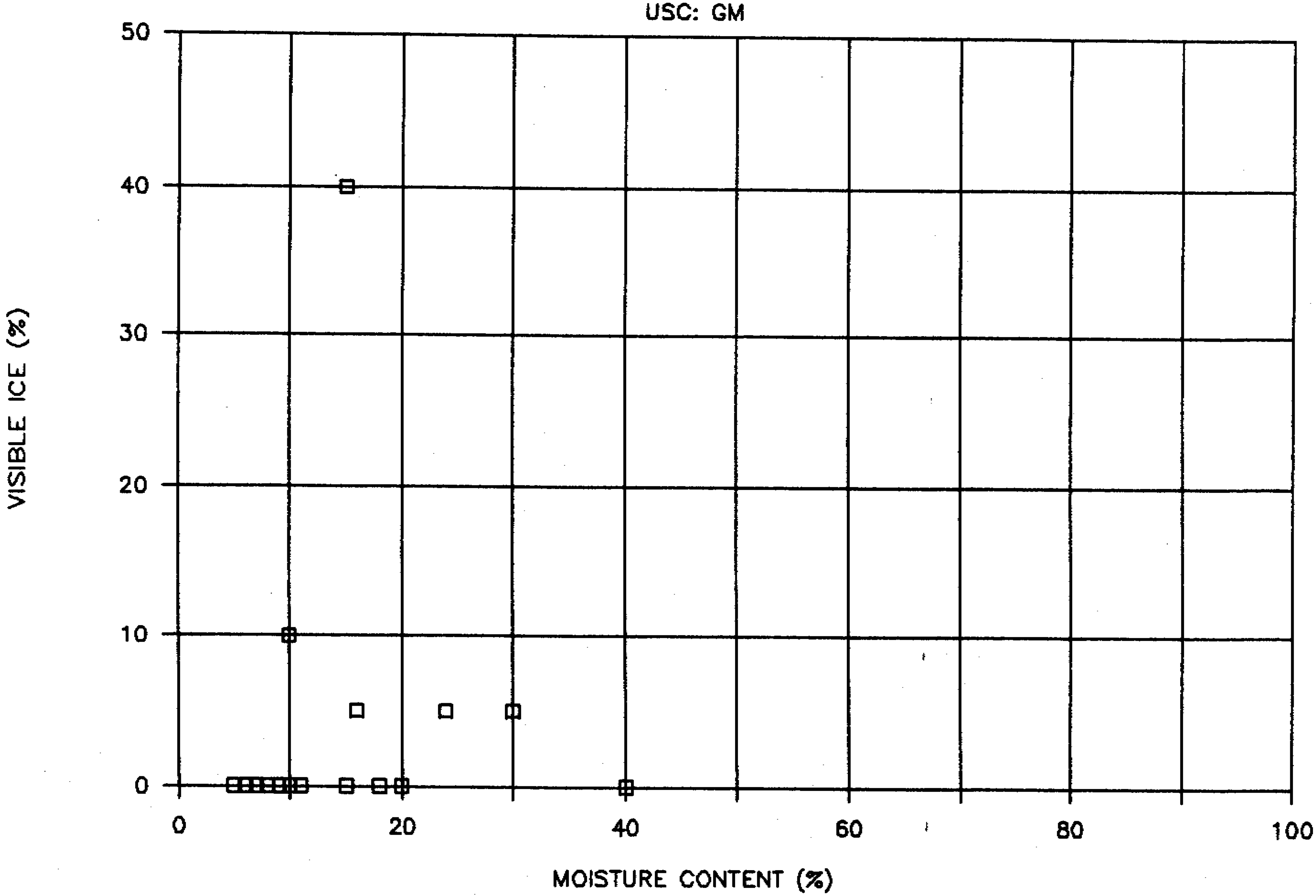


MOISTURE CONTENT vs VISIBLE ICE

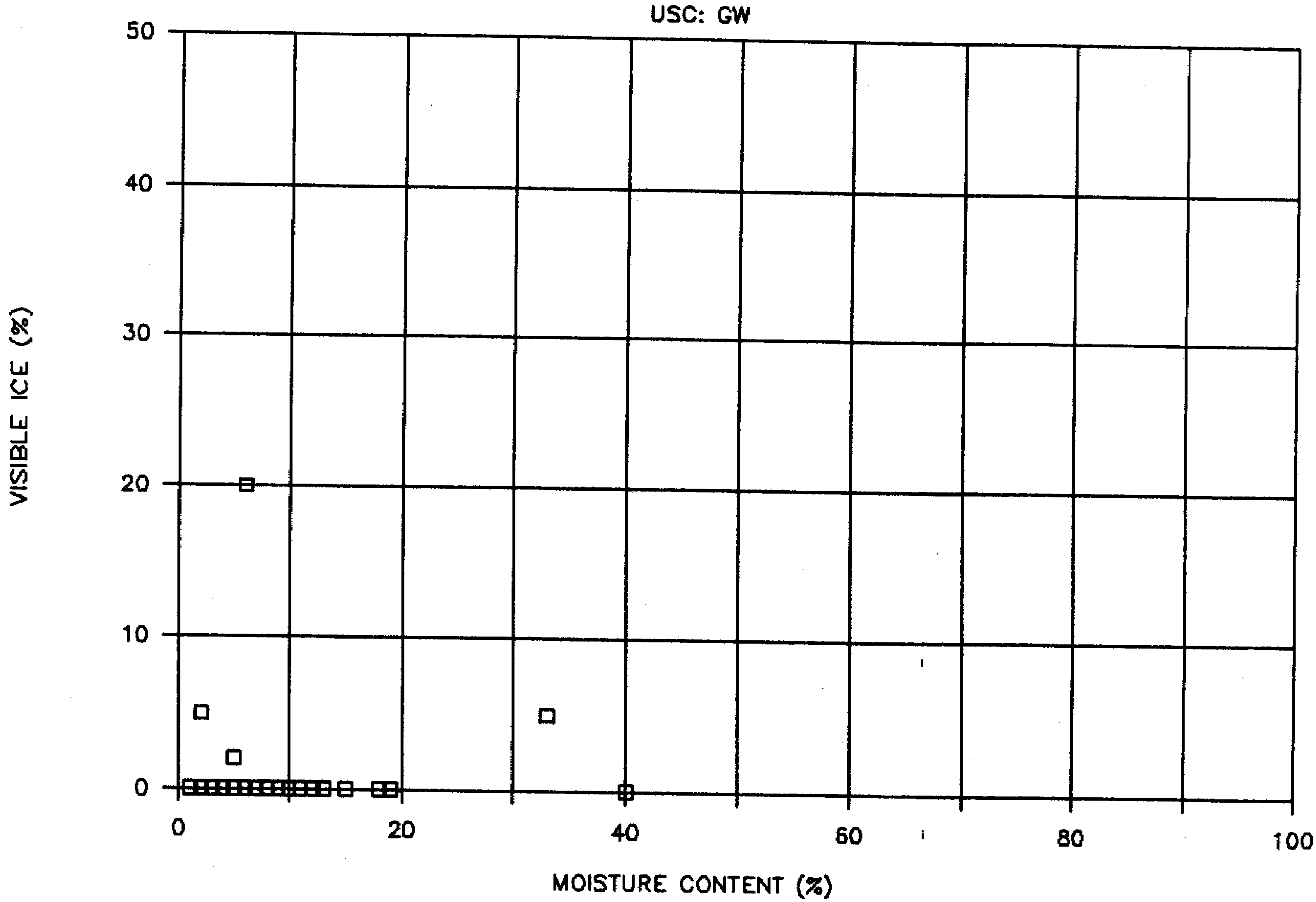
USC: GC



MOISTURE CONTENT vs VISIBLE ICE

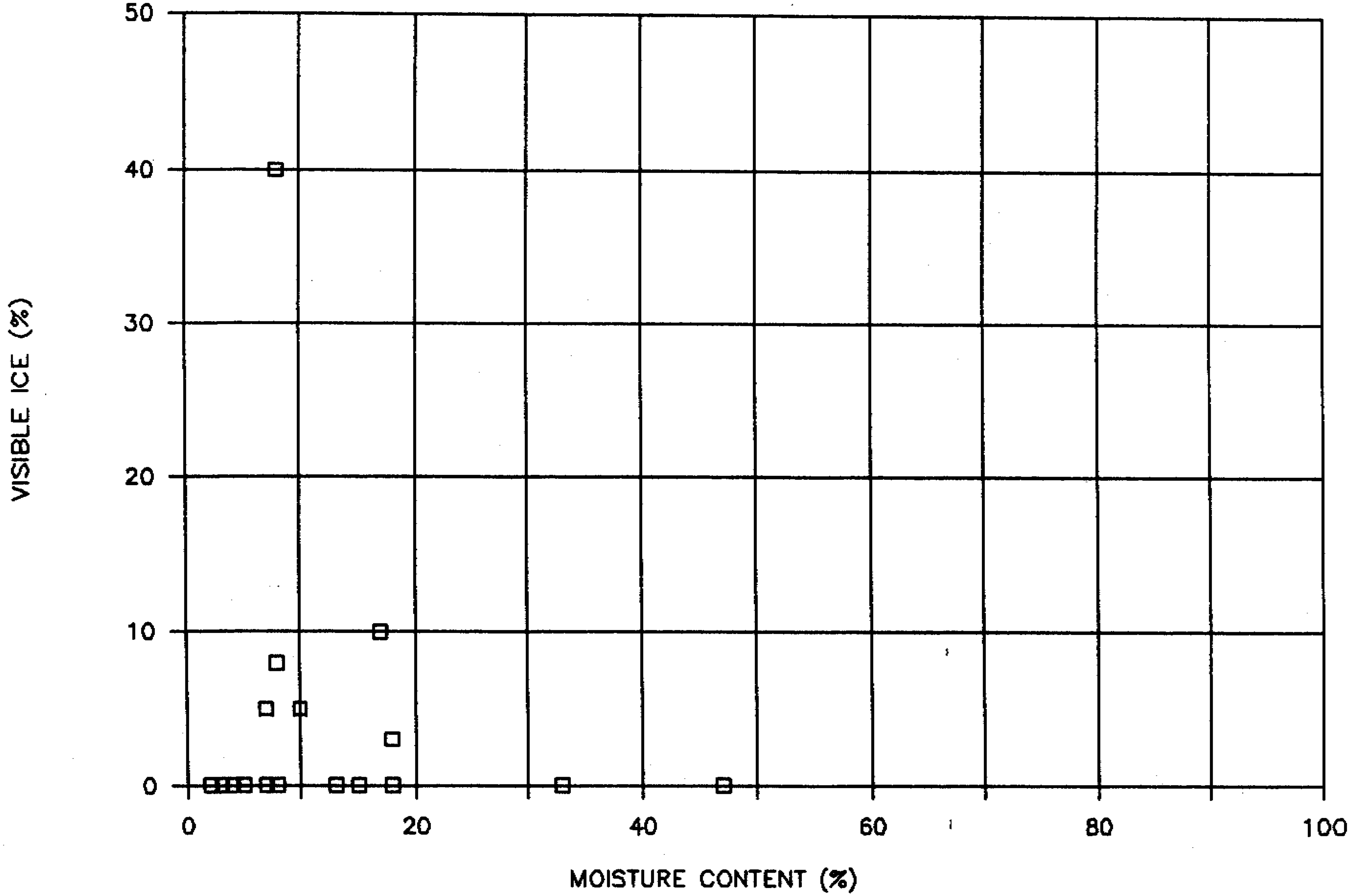


MOISTURE CONTENT vs VISIBLE ICE



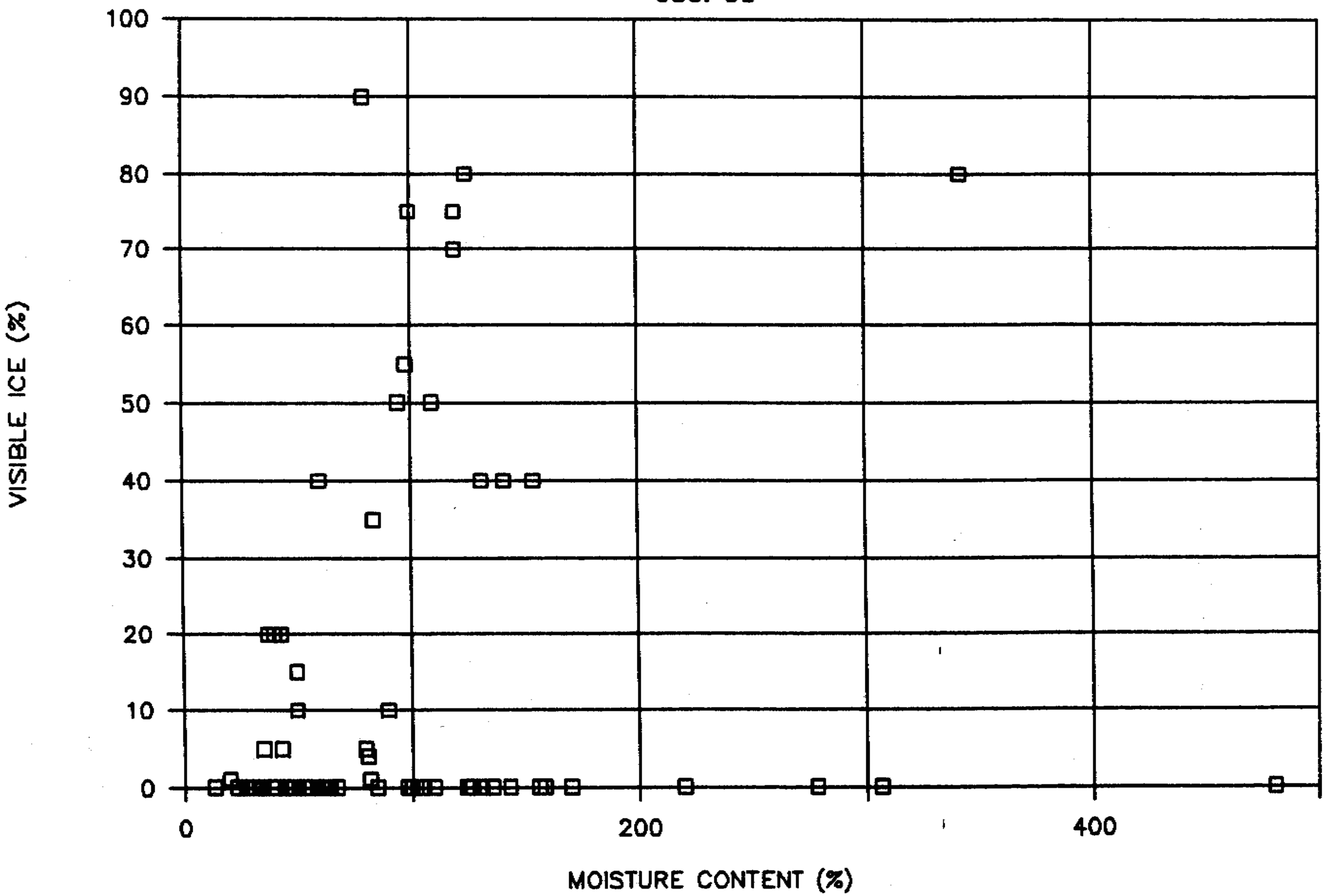
MOISTURE CONTENT vs VISIBLE ICE

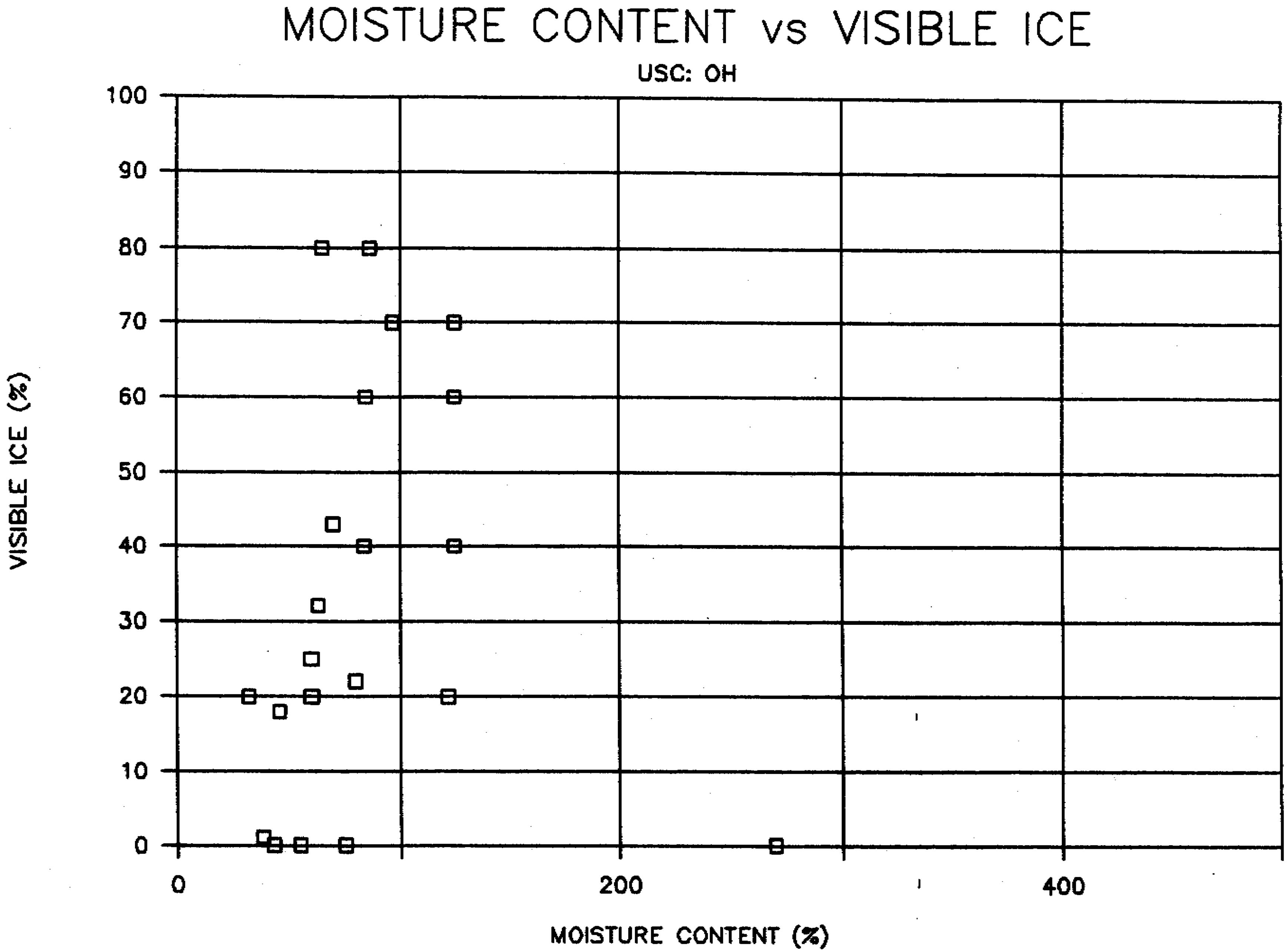
USC: GP



MOISTURE CONTENT vs VISIBLE ICE

USC: OL

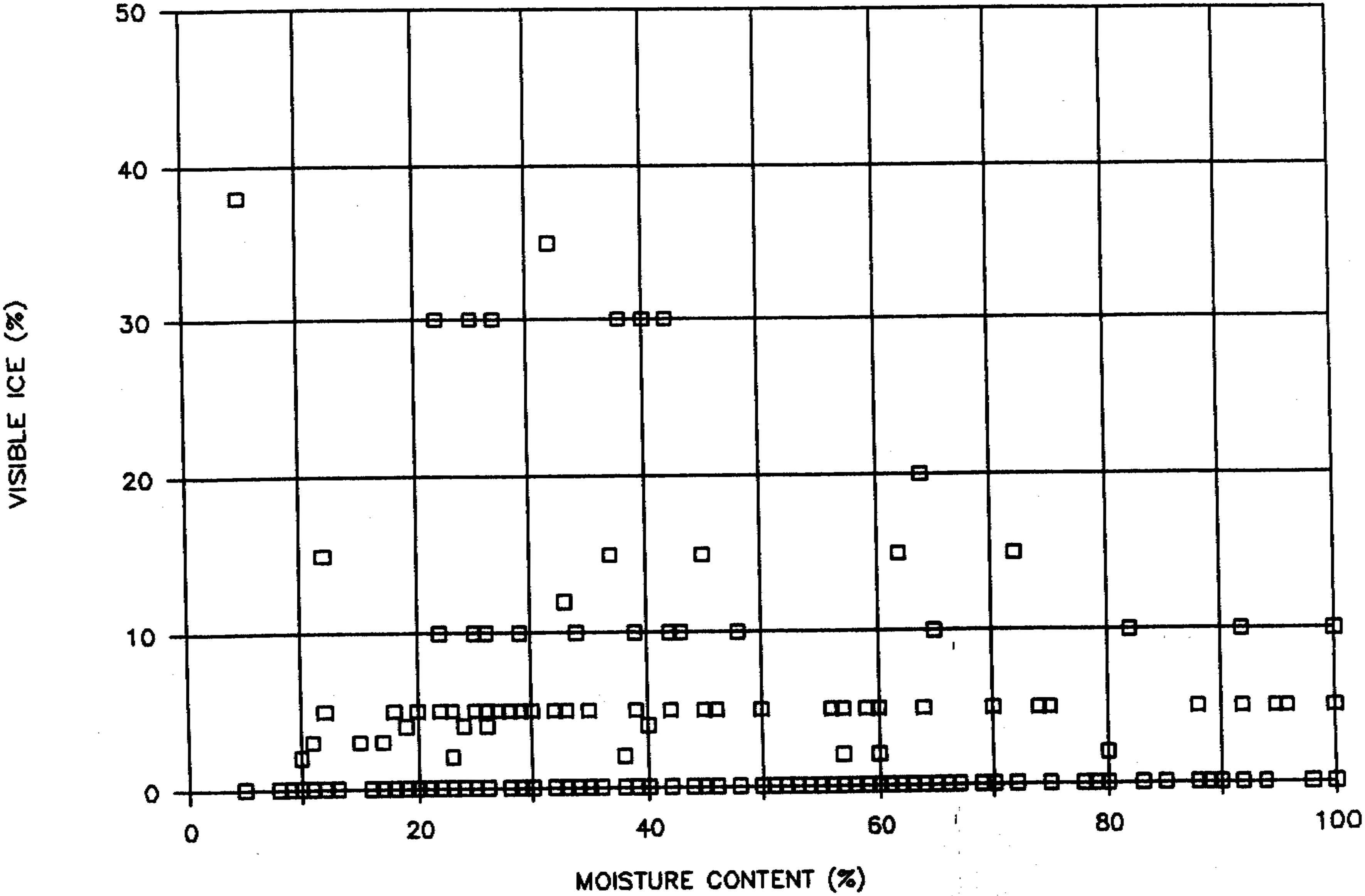




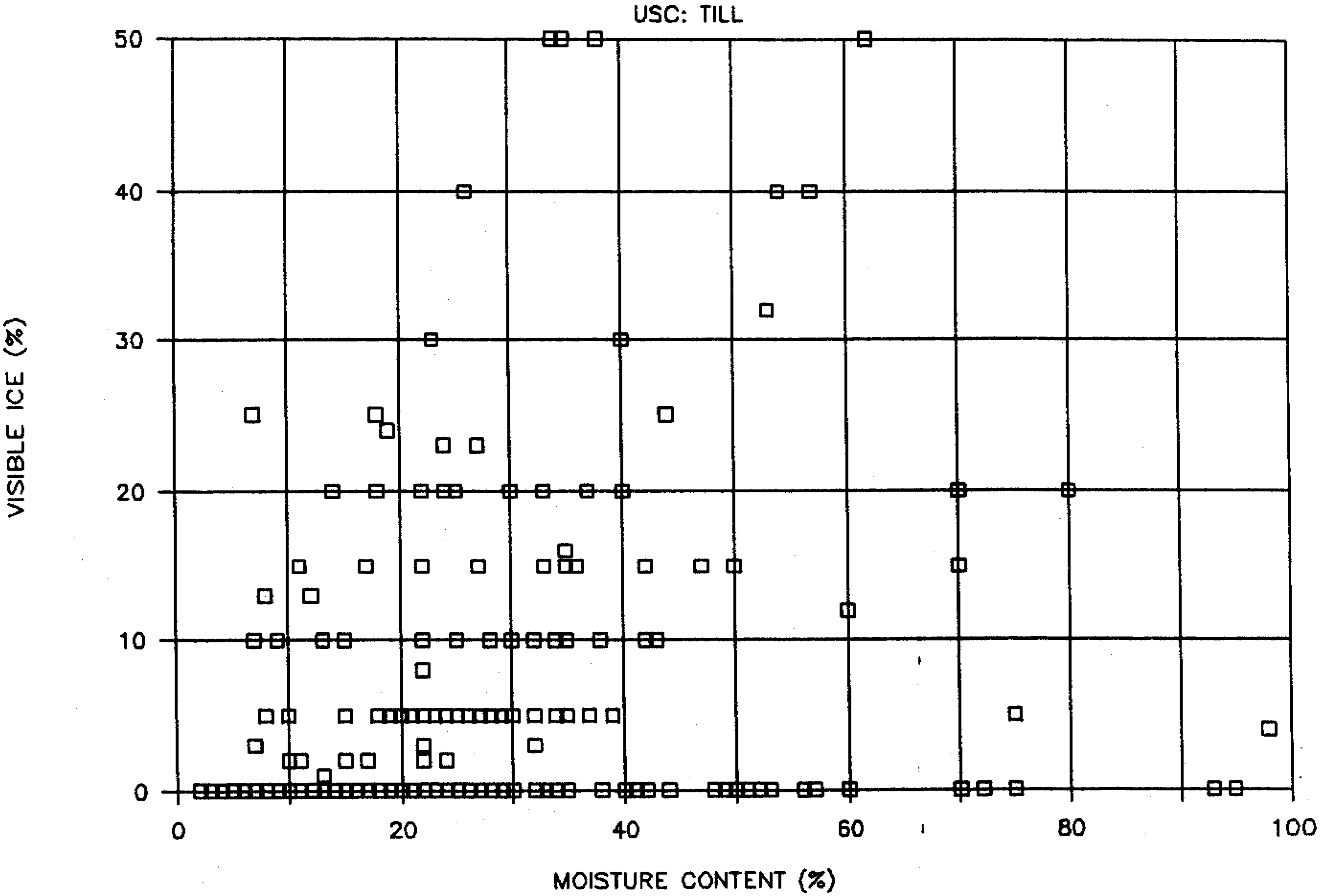
MOISTURE CONTENT vs VISIBLE ICE
USC: OH
VISIBLE ICE (%)
100
90
80
70
60
50
40
30
20
10
0
0
200
400
MOISTURE CONTENT (%)

MOISTURE CONTENT vs VISIBLE ICE

USC: PT



MOISTURE CONTENT vs VISIBLE ICE



APPENDIX C
TERRAIN TYPING LEGEND

- From Hardy Associates (1978) Ltd.
Report Entitled
"NORMAN WELLS PIPELINE PROJECT
THAW SETTLEMENT DESIGN VALUES
FOR KMP 0.00 - 868.30" Dated December 1982

TERRAIN TYPING LEGEND

The legend developed for terrain mapping of the pipeline route corridor, makes use of letters to symbolize terrain units of differing geologic origin, material type and subsurface stratigraphy. Data on erosional features, where present, are also included.

Letter Symbology

Overburden Landforms

Genetic origin (i.e. mode of deposition) is indicated by upper case letters, with landform type specified in lower case. Major landforms of each genetic type are tabulated below:

O Organic Landforms

b - patterned bog lands, including peat plateaus and palas with small collapse scars

f - ribbed (string), reticulated, and horizontal fen lands

u - undifferentiated and predominantly transitional bog-fen complexes, consisting mostly of unpatterned peatland

v - organic veneer

A Alluvial Landforms

c - channel (non-vegetated), wholly or only partly covered by water

d - delta

f - fan

p - flood plain that may or may not be inundated

t - terrace (not flooded and undifferentiated)

v - alluvial veneer

C Colluvial Landforms

a - apron

f - flow slide (mudflow and debris flow)

m - slopewash and rill wash sheet

s - slide

t - talus slope

v - slopewash veneer

E Eolian Landforms

b - sand and loess blanket

d - dunes

v - eolian veneer

L Lacustrine and Glaciolacustrine Landforms

b	-	postglacial basin
d	-	deltaic plain
p	-	nearshore and offshore lake plain
r	-	raised beach ridge
v	-	glaciolacustrine veneer

G Glaciofluvial Landforms

d	-	delta
e	-	esker, esker complex
k	-	kame, kame complex, kame terrace
p	-	outwash plain
t	-	terrace
v	-	glaciofluvial veneer

M Moraine Landforms

a	-	ablation moraine
c	-	crevasse filling
d	-	drumlin, drumlinoid moraine
e	-	end moraine
g	-	ground moraine
h	-	hummocky moraine
r	-	ridged
v	-	moraine veneer

Overburden Texture

Texture of the overburden materials is indicated by lower case letters which precede the genetic type symbol:

b	-	boulders, and/or angular blocks
c	-	clay, clay and silt and/or sand mixtures
g	-	gravel, including sandy and cobbly mixtures
m	-	silt, including minor clay and/or sand mixtures
o	-	organic component
p	-	peat
s	-	sand
t	-	till

Notes:

1. When two or more material symbols precede the genetic type symbols and no comma is used between these symbols, the first material indicated is subordinate. Symbol adjacent to genetic type designation represents the main material type.

   Example: bt - read, bouldery till.

2. When stratified deposits are expected, the symbols indicating the main materials involved are separated by a comma.

   Example: m,c - read, silt with clay beds.

Bedrock and Bedrock-Dominated Landforms

Geologic age of bedrock is not indicated (refer to available GSC maps). There is no equivalent to genetic types of overburden landforms in the symbology for bedrock landforms.

R Bedrock (Undifferentiated)

Wherever possible, basic lithological or petrographical types and structure are indicated by means of lower case letters, respectively preceeding and following the bedrock symbol.

Lithological and Petrographical Types

i	-	igneous rock (undifferentiated)
m	-	metamorphic rocks (undifferentiated)
mq	-	quartzite
s	-	sedimentary rocks (undifferentiated)
sc	-	carbonate rocks - limestone, dolomite
se	-	evaporites
sm	-	siltstones, mudstone, shale
ss	-	sandstone, conglomerate

Structure

d - steeply dipping or folded strata

h - horizontally layered strata

f - laminated

m - massive

Modifiers

Geologic processes that have modified or are currently modifying genetic materials and their surface expressions are considered as modifiers. These are used only where a relatively large portion of the map unit is modified; on-site symbols can be used to indicate modification of a relatively small portion of a map unit.

Classes

A - Avalanched
C - Channeled
E - Eroded
G - Gullied
K - Karst
P - Pitted or kettled
S - Soliflucted
T - Thermokarst

Examples of Letter Symbology

Examples of different types of symbology are given below.

Single Overburden Landforms

Main material type (till)

Subordinate material type (gravel)

gtMg - G

Genetic type (moraine)

Modifier (gullied)

Form (ground moraine)

Composite Overburden Landform

Where two or more terrain units cannot be differentiated at the scale of mapping, they are shown as a complex. Thus, where two landforms occur in approximately equal proportions, the symbols are separated by a period, for example:

tMa.pOb

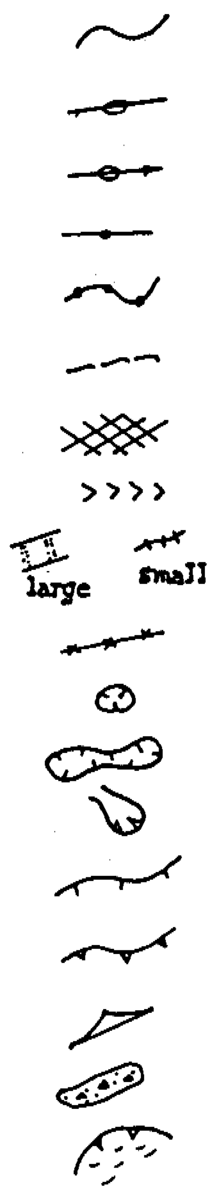
Graphic Symbols

Graphic symbols are used for features which cannot be expressed otherwise (such as boundaries) or whenever they enhance the clarity of presentation. They may not illustrate the actual size of the phenomenon.

The map scale or size of the feature (like minor stream channel, etc.) may preclude the use of certain symbols. On the other hand, several symbols permit the size of a feature to be indicated.

Main graphic symbols are shown on the following Table.

BASIC GEOLOGIC AND MORPHOLOGIC SYMBOLS



Boundaries a) geologic

Drumlin/drumlinoid ridges

Crag-and-tail

Flutings

Moraine ridge (transverse)

Minor moraine ridges

Crevasse fillings

Esker

Meltwater channel

Abandoned strandline

Sinkhole

Karst depression or cluster of sinkholes

Fan, talus cone

Escarpment in overburden

Escarpment in bedrock

Dunes

Rock and talus glaciers

Slope instability (slide)

TERRAIN TYPE CODES

Terrain Type	Computer Coded Terrain Type
Af	AF
Ap, $\frac{Cv}{Ap}$	AP
At, $\frac{Cv}{At}$	AT
Cm, Cs, Cf	CM
Cm.Ap, Cm(Ap), Ap(Cm)	CM-AP
Ct	CT
Ed, Eb	ED
Gp, Ge, Gk, Gt	GO
Lb	LB
LP, $\frac{Ev}{Lp}$, $\frac{Gv}{Lp}$, $\frac{Av}{Lp}$, $\frac{Cv}{Lp}$, sLr	LP
Lp.Mg, Lp(Mg), Mg.Lp, Mg(Lp), $\frac{Mv}{Lp}$, $\frac{Lv}{Mg}$	LP-MG
Mc, Md, Mg, Mg.Mc, Mg(Mc), Mc(Mg), Mr, $\frac{Ev}{Mg}$, $\frac{Av}{Mg}$, $\frac{Gv}{Mg}$	MG
$\frac{Cv}{Mg}$	
Ma	MA
Mh	MH
Me	ME
pOb, pOf, pOu	OU

pOb.Lp, POb(Lp), Lp(pOb), pOf.Lp, pOf(Lp), Lp(pOf) — OU-LP

$\frac{pOv}{Lp}$, $\frac{pOv}{Lp.Lp}$, $\frac{POv}{Lp(Lp)}$, $LP\left(\frac{pOv}{Lp}\right)$ — OV-LP

$\frac{pOv}{Mg}$, $p\frac{Ov}{Mg.Mg}$, $p\frac{Ov}{Mg(Mg)}$, $Mg\left(\frac{pOv}{Mg}\right)$ — OV-MG

pOb.Mg, pOb(Mg), Mg(pOb), pOf.Mg, pOf(Mg), Mg(pOf) — OU-MG

pOb.Ed, pOb(Ed), Ed(pOb), O.E, O(E), E(O), pOf.Ed — OU-ED

pOf(Ed), Ed(pOf)

pOb.Ap, pOb(Ap), Ap(pOb), pOf.Ap, POf(Ap), Ap(pOf), pOb.At, pOf.At, pOb(At), pOf(At), At(pOf), At(pOb) — OU-AP

pOb.G, pOb(G), pOf.G, pOf(G), G.pOb, G(pOb), G.pOf, G(pOf) — OU-GO

POb.R, pOf.R, $\frac{POv}{R}$, $\frac{POv}{R.R}$ — OU-RK

R, $\frac{Cv}{R}$, $\frac{Cv}{R.R}$, $R.\frac{Cv}{R}$, $R\left(\frac{Cv}{R}\right)$ — RK

$\frac{Mv}{R}$, $\frac{Lv}{R}$, $\frac{Av}{R}$, $\frac{Gv}{R}$, $\frac{Ev}{R}$

$\frac{pOv}{R}$, $\frac{pOv}{Ed}.Ed$, $\frac{pOv}{Ed}(Ed)$, $Ed\left(\frac{pOv}{Ed}\right)$, $\frac{pOv}{G}$, — OV-SP

$\frac{pOv}{G}(g)$, $\frac{pOv}{G}.G$, $G\left(\frac{pOv}{G}\right)$, $\frac{pOv}{A}$, $\frac{pOv}{A}.A$,

$\frac{pOv}{A}(A)$, $A\left(\frac{pOv}{A}\right)$

$tMg\left(\frac{tMv}{Rs}\right)$ — MG-RK

$\frac{tMr}{Rs}\left(\frac{pOr}{Mg}\right)$ — OV-RK